ECONOMIC GEOLOGY

VOL. XXXVII MARCH–APRIL, 1942 No. 2

THE ORURO SILVER–TIN DISTRICT, BOLIVIA.

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ABSTRACT.

Paleozoic (Devonian (?)) shales were intruded by Tertiary (Miocene or Pliocene) igneous rocks of acid to intermediate composition. The intrusives are shallow-seated and some were extruded. The tin-silver veins, of Pliocene (?) age, occur in rhyolite porphyry, shale, and explosive breccia near intrusive bodies of quartz-monzonite porphyry. The fracturing was caused by the intrusion of the quartz monzonite; the larger outcrops were areas of uplift, between them, relaxation occurred. The fractured zone as a whole has been uplifted so that today the vein outcrops are found in hills. The ore fluids came from the same magma body as did the quartz monzonite porphyry, and mineralization took place in two stages, an early quartz-pyrite-cassiterite stage and a late silver-sulpho-salt stage. Ore deposition took place at relatively high temperatures at a depth of 1,000 to 2,000 feet; the veins may be classed as xenothermal, relatively high temperature deposits formed at shallow to moderate depths. The average lower limit of ore that can be mined under present conditions is about 460 meters below the average level of the higher vein outcrops.

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INTRODUCTION.

ORURO is an old mining district and, although many references to it have been made in the literature most of them have dealt with the mineralogy and there has been a tendency to base interpretations of the general geology on inadequate field work. The most complete papers published to date are those by Kozlowski and Jaskolski [1] and Chace.[2] After two years of work as geologist at the Oruro mines the writer has arrived at an interpretation of the district geology, which is presented in this paper, and which differs from that of previous workers. The present paper bears chiefly on the general geology and structure; the mineralogy has been adequately described previously and only a brief review of it will be given here.

Location.—The Oruro district is located on the Bolivian high plateau 200 km southeast of LaPaz and about 15 km west of the eastern range of the Andes which forms the eastern boundary of the plateau. Oruro, one of the principal Bolivian cities, lies at the eastern foot of the isolated range of hills in which the mines are situated. The camp is at an elevation of about 3,800 meters.

History.[3]—It is probable that the first mining in the Oruro district was done by the natives during the Inca period (before the Spanish Conquest). In 1595 the outcrop of an ore-body was discovered by a Spanish Padre and mining was soon begun. A revolt by the natives in 1781 caused the mines to be closed; they were abandoned until 1846 when some of them were reopened. The Compañia Minera de Oruro was organized in 1885; today this company owns and operates all the active mines in the district.

In 1931 Lindgren [4] estimated that Oruro had produced approximately 8,000 tons of silver with a value of 200 million dollars.

[1] Kozlowski, R., and Jaskolski, S.: Les gisements argentostanniferes d' Oruro en Bolivie. Arch. de Mineral. de la Societe des Sciences de Varsovie, 8: 1–100, 1932.

[2] Chace, F. M.: Tin-silver veins of Oruro, Bolivia. Doctor's Dissertation, Harvard University, 1938.

[3] Wiener, P. M.: Les mines d'argent d'Oruro, Bolivie. Ann. des Mines, Ser. 9, 5: 511–520, 1894.

[4] Lindgren, W., and Abbott, A. C.: The Silver-tin deposits of Oruro, Bolivia. ECON. GEOL., 26: 453–479, 1931.

From 1920 to 1939 Oruro produced 489,543 kilograms of silver and 16,658 metric tons of fine tin.*

Regional Setting.—The arid "altiplano" (high plain) with its isolated ranges of hills and playas is suggestive of the basin-and-range province of western United States. The Cerros de Oruro are one of the groups of hills rising above the flat surface of the plateau. This group is about 6 km long in a north-south direction and from 1 to 3 km wide its highest points being about 300 meters above the surrounding plain.

In the vicinity of Oruro the "altiplano" is covered by a veneer of alluvial deposits. These are underlain by Paleozoic sedimentary rocks consisting of slightly metamorphosed shales and local sandstone beds. In the vicinity of the Cerros de Oruro the regional strike is approximately north-south and dips are steep.

The Cerros de Oruro owe their topographic expression to the intrusion of igneous masses, uplift, and differential erosion. The hills are elongated parallel to the regional strike of the sedimentary beds.

The age of the sedimentary rocks is uncertain because of lack of fossils but they are thought to be Devonian. Fossils found at Viacha, 195 km north of Oruro, are considered to be Silurian or Devonian.[5] In the Llallagua district, 75 km southeast of Oruro, Koeberlin [6] found fossils that he considered to be of Devonian age.

The igneous activity with which the mineralization of the district is associated took place during the Tertiary; it is assigned to Miocene or Pliocene.[7]

During the Pleistocene the Cerros de Oruro and other ranges of hills of this part of the "altiplano" stood for a time as islands in a fresh-water lake; this is evidenced by terraces of travertine containing fossils of a fresh water gastropod.[8] In the vicinity of Oruro no well defined shorelines remain; their position has to be inferred from the location of the travertine terraces.

* Data from Annual Reports of Compañia Minera de Oruro.

[5] Lindgren, W.: op. cit.

[6] Koeberlin, F. R.: Private Report to Cia. Minera de Llallagua, 1919.

[7] Berry, E. W.: Fossil plants from Bolivia and their bearing upon the age of uplift of the Eastern Andes, Proc. U. S. Nat. Museum, 54: 103–164, 1917.

[8] Kozlowski, R., and Jaskolski, S.: op. cit., p. 15.

PETROGRAPHY AND PETROLOGY.

The detailed geology of the mine area is shown in Fig. 1.

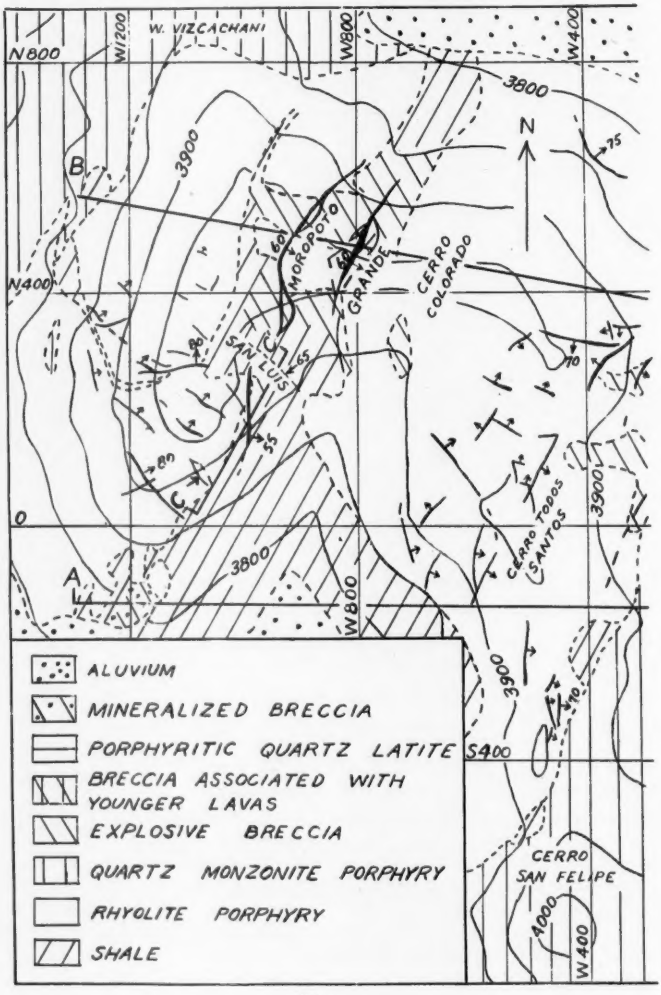


FIG. 1.

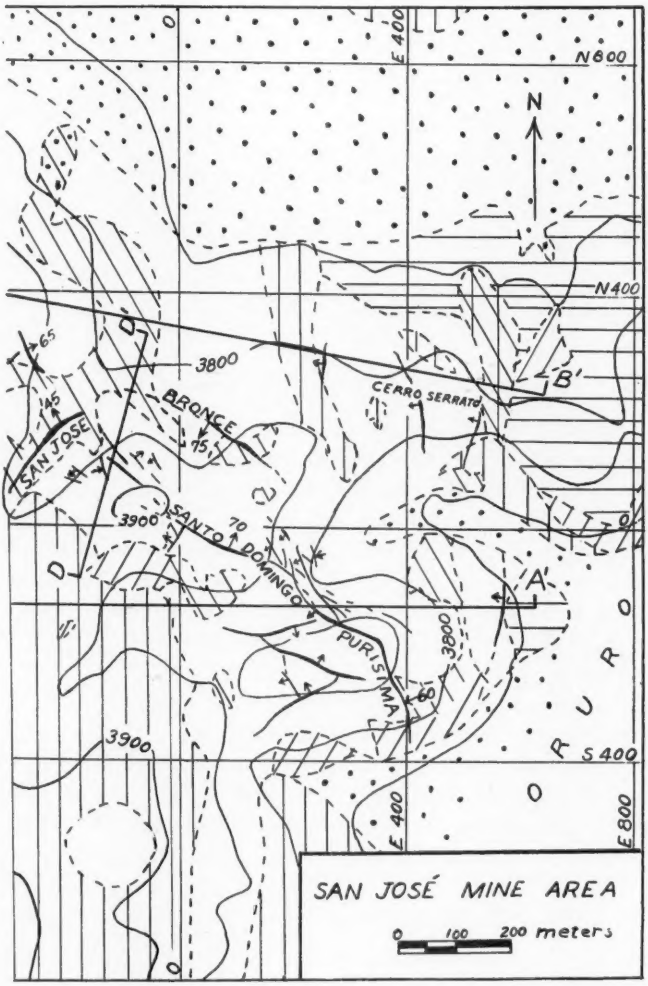


FIG. 1 (*continued*).

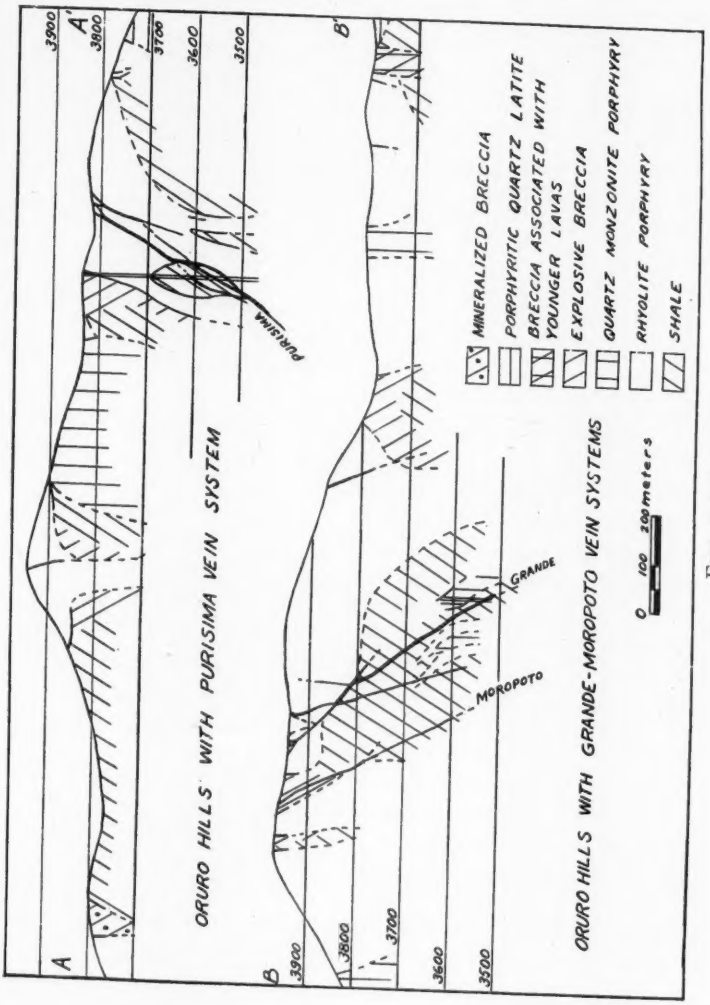
GEOLOGIC COLUMN FOR THE ORURO DISTRICT.

Cenozoic	Quaternary	Recent	Alluvial Deposits
		Pleistocene	Alluvial and Lake Deposits
	Tertiary	Pliocene (?)	Porphyritic Quartz Latite-Younger Lavas
			Breccia associated with the younger lavas; composed of fragments of quartz latite and shale; of explosive origin
			Explosive Breccia; composed of fragments of rhyolite in a groundmass of fragmental shale
			Quartz Monzonite Porphyry; shallow intrusives
			Rhyolite Porphyry; shallow intrusives and lavas
Paleozoic		Devonian (?)	Shale; with minor amounts of sandstone, argillite, and quartzite

Paleozoic (Devonian (?)) Sedimentary Rocks.

Shale.—The sedimentary rocks are here classified as shale; some workers have called them slate, but the slaty portions are better described as argillite since secondary cleavage is lacking. In the immediate mine area there are only a few sandy layers in the shale; but in the Iroco Hills, west of the mines, the sandy beds in the shale locally may be as much as fifty per cent. The attitude of the shale beds in the vicinity of the igneous bodies changes abruptly over short distances and cannot be used as a guide to regional structure.

The shale outcrop near the mines is small (Fig. 1) but in the mine workings the area increases downward (Figs. 2, 3, 4, and 5). Over large areas in the lower workings contact metamorphism has changed the shale into a light gray, massive, rock composed of sericite and quartz. In places near igneous contacts, the organic matter of the shale has been concentrated into areas about 3 mm in diameter, which give the rock a spotted appearance. Silicification of the shale near the major veins and igneous contacts is common but not extensive except on the lower levels, where some tourmalinization also occurs near igneous contacts.


A
A'
B
B'
3900
3800
3700
3600
3500
PURISIMA
ORURO HILLS WITH PURISIMA VEIN SYSTEM
GRANDE
MOROPOTO
ORURO HILLS WITH GRANDE-MOROPOTO VEIN SYSTEMS
0 100 200 meters
MINERALIZED BRECCIA
PORPHYRITIC QUARTZ LATITE
BRECCIA ASSOCIATED WITH YOUNGER LAVAS
EXPLOSIVE BRECCIA
QUARTZ MONZONITE PORPHYRY
RHYOLITE PORPHYRY
SHALE

FIGS. 2 AND 3.

Tertiary (Pliocene (?)) Igneous and Related Rocks.

Rhyolite Porphyry.—The oldest igneous rock in the district and the most exposed in the mine workings is a medium to dark gray porphyry with about 40 per cent of phenocrysts, of which three-fourths are white altered feldspar and one-fourth are quartz. Pyrite is universally distributed through this rock, and averages about 1 to 2 per cent, but locally along fractures may reach 35 per cent of the rock. Hydrothermal alteration is so extensive that fresh specimens are rare. Disregarding alteration products, the approximate mineral composition appears to have been 60 per cent feldspar (⅔ orthoclase and ⅓ albite); 25 per cent quartz; and 15 per cent biotite. It is classified as a rhyolite porphyry.

Hydrothermal alteration may be divided into the following stages on the basis of decreasing temperature: (*a*) Development of tourmaline and allanite.—Tourmaline is widespread in the Itos mine and in the lower levels of the other sections. Allanite (tentative identification) was developed locally in the Itos mine and in a few places in the lower levels of the other mines. Some pyrite may have been formed during this stage. (*b*) Development of epidote from the feldspars, chlorite from the biotite, and pyrite.—Epidote is more widely distributed than tourmaline and allanite and is not confined to the lower levels. Some pyrite was formed during this stage. (*c*) Development of sericite and quartz from feldspars, and of talc from the chlorite and pyrite.—This stage of alteration was the most intensive and extensive and affected all of the rhyolite porphyry bodies. At the end of the hydrothermal alteration considerable pyrite had been introduced.

The rhyolite porphyry formed dikes that widen toward the surface, and spread out as surface flows. This conclusion is based upon the following evidence: (1) The small area of shale outcrops and the underground evidence that rhyolite porphyry outcrops are underlain at shallow depth by shale; (2) the decrease in the size of the rhyolite porphyry bodies with increasing depth; (3) porphyritic texture and the presence of flow structure and a slightly finer grain in the rhyolite porphyry near the surface, although not direct evidence, favor the above conclusion. The

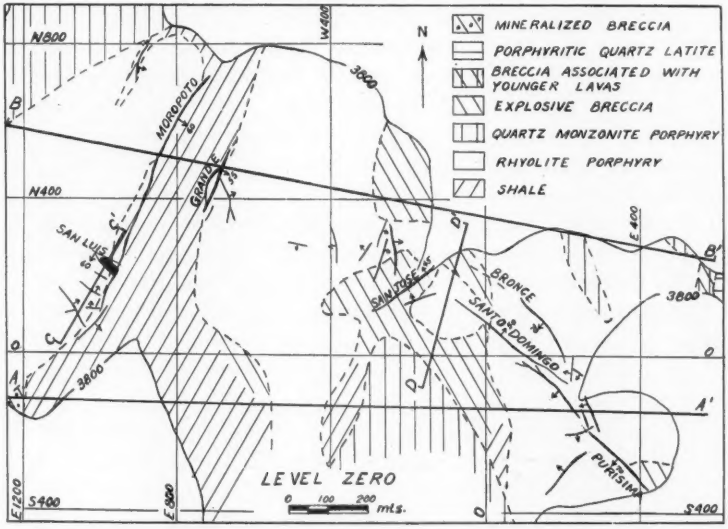


FIG. 4.

rhyolite bodies might be eroded laccoliths, but it is thought that there has not been enough material removed by erosion to support this theory. The outcrop of the rhyolite porphyry gives no indication of the shape of the bodies at depth. At the horizon of the lower mine levels the rhyolite porphyry dikes have a width of from 100 to 500 meters in an east-west direction and a length exceeding 800 meters (Figs. 1 and 5). Small dikes and sills penetrate the surrounding shales along the main contacts.

Along some of the rhyolite porphyry-shale contacts there is some contact breccia consisting of shale fragments in a porphyry groundmass, which differs from the explosive breccia which latter is composed of fragments of rhyolite porphyry in a crushed shale groundmass.

Other Igneous and Related Rocks.—The remaining rocks of the district except the alluvial deposits, are part of a group formed during the same period of igneous activity at approximately the same time. They include:

(1) Quartz monzonite porphyry, which is a medium, dark greenish-gray, porphyry with about 50 per cent of phenocrysts. About six-tenths of these are feldspar, two-tenths are quartz, and two-tenths are biotite altered to chlorite. Perhaps 1.5 per cent of the rock is composed of large sanidine phenocrysts averaging 1 cm in length but with a maximum length of 11 cm.

This rock originally consisted of 65 to 70 per cent feldspar, nearly equally divided between orthoclase and andesine; 15–20 per cent biotite; and about 15 per cent quartz. It is coarser grained than the rhyolite porphyry and contains more phenocrysts. Under the microscope the groundmass shows a fairly well developed monzonitic texture, which is lacking in the groundmass of the rhyolite porphyry. For these reasons it has been classified as a quartz monzonite porphyry.

Hydrothermal alteration consisted of the development of sericite from the feldspars and of chlorite from the biotite.

The quartz monzonite porphyry was intruded as small stocks and large dikes (Fig. 1), the largest body being about 1.2 by 1.8 km across. A few small dikes have been encountered underground, but in general the workings are in older rocks around the periphery of the quartz monzonite bodies. Dikes of quartz monzonite porphyry cut rhyolite porphyry bodies; this may be seen both on the surface and in the mine (Figs. 1, 3, 4, and 5).

(2) Explosive breccia.—This rock is composed of light gray rhyolite porphyry fragments in a dark gray groundmass of crushed shale. The porphyry fragments vary in diameter from several millimeters to more than a meter and may make up from less than 1 per cent to more than 80 per cent of the volume of the breccia, and average about 20 per cent. In most of the breccia the porphyry fragments are angular but in some of the breccia dikes they have been rounded. The fragments are highly altered to sericite, quartz, and pyrite. Under the microscope the texture is seen to be the same as that of the rhyolite porphyry of the adjacent igneous bodies; the monzonitic texture of the groundmass of the quartz monzonite porphyry is notably absent. Microscopic study confirms the megascopic determination of the character of the ground-

mass of the breccia. In general the amount of porphyry fragments in the breccia decreases away from the rhyolite porphyry contacts, and the outer contact between breccia and shale is gradational.

The explosive breccia occurs as pipes, dikes, and irregular bodies that conform in a general way to the rhyolite porphyry-shale contacts. No breccia bodies occur in the shale or in the rhyolite porphyry far from their mutual contact, but not all parts of the contacts have breccia bodies. As far as is known, breccia bodies were not formed along contacts between quartz monzonite porphyry and shale, but may extend up to it (Fig. 4). The horizontal extent of the breccia bodies is at a maximum near the surface and decreases downward. There were two stages of breccia formation, since normal breccia is cut by dikes of finer grained breccia that contain well-rounded fragments of rhyolite porphyry.

The nature of the breccia indicates that it must have been formed by explosive agencies, and since the rhyolite porphyry fragments are angular, brecciation must have been subsequent to solidification. The shape of some of the breccia bodies is the same as that assumed by intruded magmas; they form dikes cutting rhyolite porphyry. It is possible that the shaly material making up the groundmass of the breccia may have been made soft by igneous heat, permitting it to behave under pressure as a mud. Probably the explosive energy and possible heat necessary for the breccia formation resulted from the same igneous activity that gave rise to the quartz monzonite. Breccia formation is thought to have taken place shortly after the quartz monzonite intrusion because some breccia bodies enclose major veins and because a similar breccia outcropping on Cerro Serrato (Fig. 1, coordinates N. 150 to 400, E. 600) contains fragments of quartz latite, a volcanic phase of the monzonite. Avenues of relief for the explosive energy that caused the breccia were localized by the contacts between rhyolite porphyry and shale. It is no coincidence that the explosive breccia bodies and the veins occur in nearly the same area. If all of the igneous rocks of the district are assumed to be of the same

age, as has been assumed in the past, it is hard to explain satisfactorily the formation of the explosive breccia.

The formation of explosive breccia took place before the formation of the fractures that later became veins, because in many places veins occur in the explosive breccia.

(3) Breccia associated with the younger lavas.—At the eastern side of the mine area (Fig. 1, coordinates N. 150 to 400, E. 600) there is a dike-like outcrop of breccia that consists of a mixture of quartz latite and shale fragments averaging about 5 mm in diameter; roughly two-thirds of the fragments are quartz latite. Immediately to the east of this outcrop flows of quartz latite cap the hill. This breccia is undoubtedly of explosive origin and was probably formed along the channelway through which the lavas were extruded. It is thought to be slightly younger in age than the intrusives of quartz monzonite porphyry.

(4) Younger Lavas.—Two closely related types have been identified, quartz latite and dacite, both porphyritic, and extrusive equivalents of the quartz monzonite porphyry. Most of these lavas are thought to be contemporaneous with the quartz monzonite porphyry; but some of them in the area north of the mines are regarded as slightly earlier, because: (*a*) they are altered more than other lavas of similar composition; (*b*) in places they appear to be cut by dikes of quartz monzonite porphyry; (*c*) in places the contact between them and the quartz monzonite is gradational, the sequence observed being pure quartz latite, nearly square blocks of quartz latite defined by joints about a meter apart and concentrically altered inward from the joints (caused by solutions from the quartz monzonite), quartz latite of which the joints are occupied by material closely resembling the quartz monzonite in color (thought to have been formed from the quartz latite by solutions from the quartz monzonite), pure quartz monzonite.

Alluvial and Lake Deposits.

These are of interest because in places they contain economic tin placers. The placers occur on bedrock in canyons that lead out of the hills; the deposits were built up where the intermittent

streams from the mineralized portions of the hills entered the Pleistocene lake that formerly occupied this part of the "altiplano." There is an abrupt change in the stream gradients at this point. The placer tin is now covered by from 5 to 15 meters of worthless alluvium.

STRUCTURAL GEOLOGY.

District Structure.

The intrusions of the igneous bodies making up the Cerros de Oruro took place along a zone of steeply dipping beds of Paleozoic sediments. The Iroco Hills, west of the Cerros de Oruro, consist of a faulted anticline overturned to the eastward. Shale exposures in the Cerros de Oruro have been so disturbed by nearby intrusions that the local structure of the sedimentary rocks previous to the intrusions cannot be determined exactly, nor is the relation of the Cerros de Oruro to regional Andean structure apparent from the local geology. The north-south elongation of the hills is due to the regional strike of the sedimentary beds, which has localized and elongated the intrusives. This is especially true of the ore-enclosing rhyolite porphyry, but the younger quartz monzonzite porphyry bodies tend to be more equidimensional. Locally the attitude of the shale beds has had but little effect on the shape of the intrusives.

Pre-Mineral Fracturing in the Mine Area.

Location.—The highly mineralized part of the district consists of an area of older rocks lying between two large quartz monzonite porphyry intrusives. One of these intrusives outcrops in the San Felipe area (Fig. 1). The other outcrops in the San Pedro-Vizcachani area in the northern part of the district (only part of which is shown in Fig. 1).

The mineralized area may be divided into five major fracture systems that persist to appreciable depths; they are the Purisima, Bronce (the Santo Domingo vein is part of the Bronce system),

San José, Grande-Moropoto, and San Luis. Fig. 1 shows the location of these systems. The Purisima (Fig. 5) and Bronce are regarded as separate fracture systems, because on the lower mine levels the difference between their average strikes is nearly 90°. The Grande and Moropoto (Figs. 4, 5), fractures are parallel and about 150 meters apart; they are considered as members of one system because they have apparently been formed by the same stresses. These major fracture systems may individually be perpendicular to, or parallel with, major rhyolite porphyry dikes.

In addition to these major systems with their related smaller fractures, there are several minor groups of veins that have been worked near the surface. These occur at some distance from, and are independent of, the major fracture systems, but are also thought to have been formed by the stresses set up by the intrusion and solidification of the quartz monzonite porphyry.

General Characteristics of Fracture Systems.—(1) Fracturing is more complex near the present surface than it is at depth (Figs. 3, 6). (2) The dip of some of the main fractures steepens with depth. (3) The fracture systems are located around the edges of and between the monzonite porphyry intrusions. (4) The exact location and attitude of the main fracture zones were influenced by the location and attitude of large rhyolite porphyry dikes in shale, as well as by the location and shape of explosive breccia bodies. The larger ore bodies seem to have been formed where the individual fractures are best defined and correspond to the average trend of the main fracture zone. Zones where cracking and brecciation were most extensive are the sites of the largest ore bodies. (5) A fracture system consists of a main fracture or fracture zone and numerous associated minor fractures. These latter may be: (*a*) conjugate and parallel caused by the same stresses that formed the main fracture; (*b*) branch fractures, caused by adjustments between parts of the larger blocks, and slumping in the hanging well of the main fractures; and (*c*) fractures caused by a combination of causes *a* and *b*. There may thus be mineralization in the walls of the main vein as in the San Luis fracture, Itos mine.

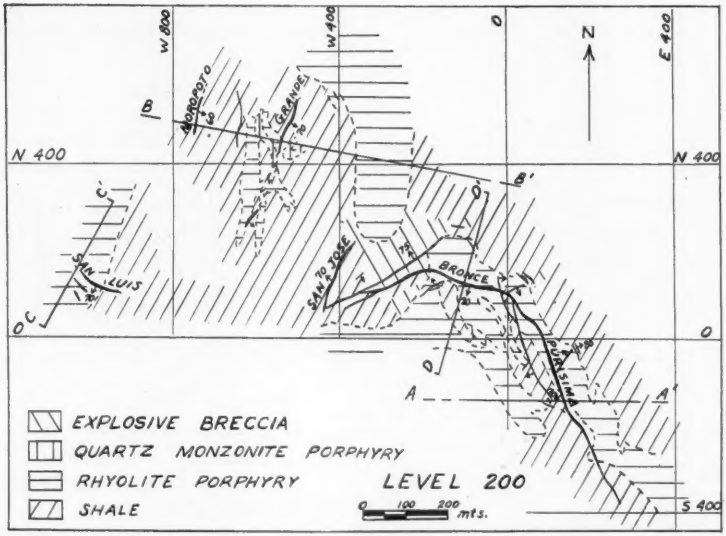
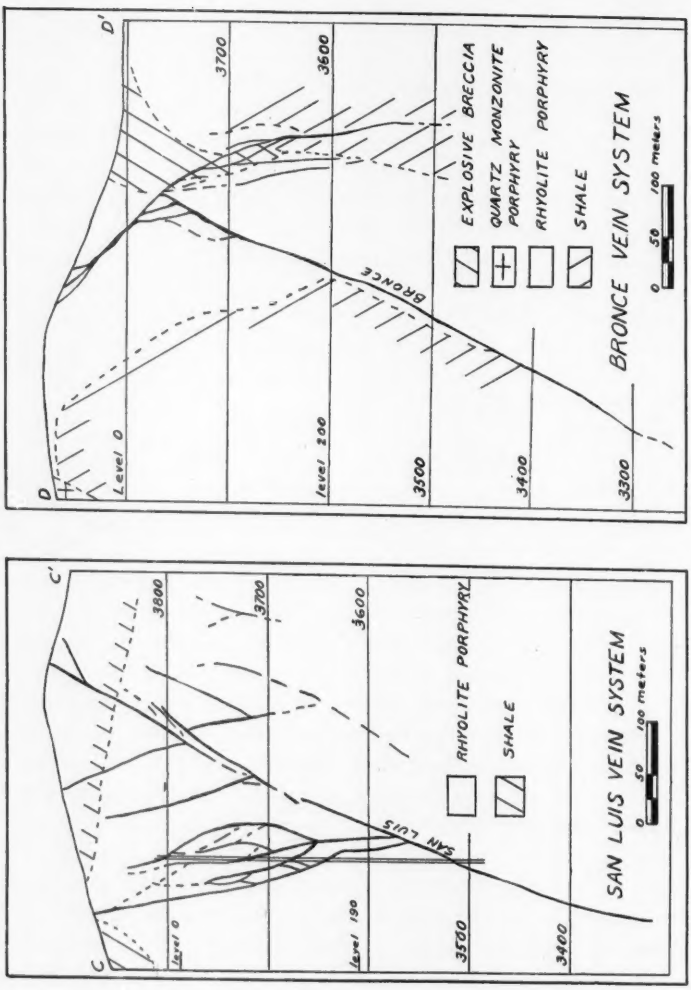


FIG. 5.

The Purisima and Bronce systems, in contrast to the others, do not steepen with depth (Figs. 1, 2, 5, 6, 7). In some places where they cut inclined igneous contacts, displacement suggests that reverse movement has taken place. The displacement of a contact between rhyolite porphyry and shale indicates that normal faulting movement with a vertical component of about 90 meters has taken place along the Grande fracture system.

The San Luis fracture system occurs in rhyolite porphyry near the shale contact. Practically all of the mineralization is in the porphyry; the fractures die out rapidly where they penetrate the shale. In the rhyolite porphyry near the San Luis fracture system there are minor fractures, mostly several meters apart but in places so closely spaced as to form sheeted zones. The main fractures in the porphyry, normal to the contact, converge in the direction of the contact. It is probable that vertical movement was greatest at the contact and decreased away from it into the por-


D
D'
Level 0
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3700
3600
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3300
BRONCE
EXPLOSIVE BRECCIA
QUARTZ MONZONITE PORPHYRY
RHYOLITE PORPHYRY
SHALE
BRONCE VEIN SYSTEM
0 50 100 meters
C
C'
Level 0
Level 100
3800
3700
3600
3500
3400
SAN LUIS
RHYOLITE PORPHYRY
SHALE
SAN LUIS VEIN SYSTEM
0 50 100 meters

FIGS. 6 AND 7.

phyry. Under these conditions, rotational movement along the main non-parallel fractures would set up stresses that probably would cause the development of the complex minor fractures. The ore bodies of the Itos mine were indirectly localized by the east contact of the large rhyolite porphyry body; for this reason steps are being taken to locate and prospect the west contact.

Characteristics of Individual Fractures.—These are: (1) The vein mineralization involves deposition along a series of parallel, curving, and overlapping cracks. The curving parts of the fractures departing from the main zone rarely contain more than a thin stringer of the ore minerals. (2) Individual fractures are commonly irregularly "S" shaped or arc like. (3) Fractures generally are longest down the dip and may overlap in plan and section. (4) The movement along fractures is thought to have been relatively small. (5) Striae in places indicate hinge movement along pre-mineral fractures. (6) Fractures do not intersect, but die out before this occurs, and no bonanzas occur in the vicinity of such approach. (7) Fractures do not offset one another appreciably. (8) Brecciation of wall rocks is present along most of the larger veins near the surface, and slickensides in lower levels. Numbers 1 to 5 are from Chace.[9]

Relation of Fractures to Wall Rocks.—Each wall rock fractured differently and the location and shape of the fractures were influenced by the wall rock assemblage.

Thus the rhyolite porphyry fractured as a brittle material and was conducive to the formation of persistent fractures.

Shale behaved like a semi-plastic material and hence did not yield persistent fractures; consequently where fractures pass from rhyolite into shale they die out shortly. In one case, however, a strong vein, the Grande, extended down into the shale from —50 to —290 meters because the rock was locally metamorphosed and hence more brittle.

The explosive breccia also fractured like a semi-plastic material, but less so than the shale because of included rhyolite porphyry

[9] Chace, F. M., op. cit., pp. 52–57.

FIGS. 6 AND 7.

fragments. In addition, because the explosive breccias were zones of weakness, they influenced the loci of fracturing to some extent, as for example, the San José.

Contacts between rhyolite porphyry and shale were not favorable vein loci.

Origin of the Fractures.—When the mineralized area as a whole is considered, the fractures seem to be haphazardly arranged and their origin cannot be explained by stresses of the same type acting in the same direction over the entire district. However, when the quartz monzonite porphyry bodies are taken into consideration, the fractures are seen to be more or less systematically arranged around them; therefore, the fractures are thought to be directly related to the porphyry bodies. The larger quartz monzonite porphyry bodies (*i.e.* Cerros San Felipe and W. Vizcachani) are considered to be areas that have been uplifted by igneous intrusion. The area between them (*i.e.* Cerros Todos Santos and Colorada, Fig. 1) is an area that collapsed. Thus, the fractures of the Purisima and Bronce systems may be interpreted as reverse faults dipping toward the area of uplift from near its margins, caused either by the upthrust of the intruding magma or its vapor pressure. The fractures of the San José, Grande-Moropoto, and San Luis vein systems, may be interpreted as normal faults around an area that collapsed because of non-support. This explanation is advanced only for the initiation of the major fractures; the details of fracture formation undoubtedly became more complex as the process continued. Local details of structure were influenced by the physical characteristics of the intruded rocks.

In the opinion of the writer not all of the fracture systems could have been formed directly by gas pressure generated by the cooling magma. The Purisima and Bronce fracture systems could have been formed in this way; but the vapor pressure hypothesis alone could not apply to the San José, Grande-Moropoto, and San Luis systems because they partially surround and dip toward an area that field evidence indicates to be comparatively low in the roof of the stock. If it is assumed that these fracture systems partially

surround and dip toward the regional high point of the stock, it becomes difficult to understand why the Purisima and Bronce systems show such a close relation to the outcrop of the San Felipé-Lulicancho intrusive body, comparatively small from a regional point of view.

Vapor pressure of the cooling magma and shrinkage due to crystallization of the magma may have played an important part in accentuating the fractures that were initiated by the upthrust of the intruding magma and slumping of areas between the high points of the roof of the intrusive.

There were two stages of mineralization in the district (see Mineralogy). After the early stage (pyrite-cassiterite) the veins became sealed and were reopened, with resulting brecciation of early stage vein material, at the beginning of late stage (sulphosalt) mineralization. Reopening of the veins may have been caused either by renewed fault movement or by vapor pressure of the magma which built up after the veins became sealed following the early stage mineralization.

Post-Mineral Fracturing in the Mine Area.

No faults have been observed in the mine area that can be established as post-mineral in age. There are numerous cases in which a fracture may be followed along the strike from ore into barren gouge. However, this condition is attributed to the fact that the gouge excluded mineralizing solutions from some parts of the fracture.

ECONOMIC GEOLOGY.

Mineralogy.

Numerous mineralogical studies have been made of the Oruro deposits, and a large number of minerals have been described. A list of those which have been reported from the district has been compiled by Chace [10] and is given below:

[10] Chace, F. M.: op. cit., p. 81.

Hypogene Sulphide Minerals		Hypogene Gangue Minerals	Oxidized Zone Minerals
Pyrite	Plagionite	Quartz	Limonite
Cassiterite	Wurtzite	Sericite	Jarosite
Arsenopyrite	Hematite	Kaolinite	Melanterite
Tetrahedrite	Pyrrhotite	Alunite	Marcasite
Andorite	Boulangerite	Tourmaline	Metastibnite
Zinkenite	Meneghinite	Augelite	Chalcedony
Jamesonite	Chalcostibite	Wavellite	Hydrohematite
Bournonite	Semseyite	Apatite	Anglesite
Franckeite	Stibnite	Barite	Cervantite
Galena	Wolframite	Siderite	Cerussite
Stannite	Ruby Silver	Ankerite *	Covellite
Sphalerite	Stephanite		Cerargyrite
Chalcopyrite	Freieslebenite		
Miargyrite	Marcasite		

* This mineral has been observed by the writer in the wide veins west of Cerro San Pedro; it has not been seen in the veins in the Cerros de Oruro.

The hypogene mineralization of the district has taken place in two distinct stages, separated by a structural break. The mineralization of the early stage consists of pyrite, quartz, and cassiterite. The mineralization of the late stage is complex and consists chiefly of a large number of sulpho-salts.

If the outlying parts of the district are considered, it may be possible to add a third stage of mineralization, although evidence for this is inconclusive. In the Iroco Hills, west of the mines, there are numerous quartz veins some of which carry native gold. In the small hills west of San Pedro (northwestern part of the district) there are two large quartz-ankerite veins that contain small amounts of silver and tin. The location of these veins away from the main area of mineralization suggests that they may represent a comparatively low temperature stage of the same metallogenetic epoch of which the tin-silver veins are earlier members. The fact that there are a few narrow quartz veins in the outlying parts of the mineralized areas of the Cerros de Oruro is regarded as evidence in favor of this conclusion.

Stages of Hypogene Mineralization.—(*a*) *Early Stage.* The important minerals of this stage are pyrite, quartz, and cassiterite, named in order of abundance. Of the total, pyrite makes up roughly 85 per cent, quartz 15 per cent, and cassiterite may con-

stitute 5 per cent of the vein material in the ore-shoots but much less in the veins as a whole. Most of the recoverable tin of the veins, present in the form of cassiterite, was deposited during this stage. The tin present in the late stage tin minerals, franckeite and stannite, presents such a difficult recovery problem that they do not constitute an important source of tin even where they occur in appreciable quantities.

It is estimated that about two-thirds of the vein material of this stage was deposited by replacement of wall rocks and one-third by filling of open spaces in the fracture zone.

Microscopic study indicates that the deposition of quartz and pyrite began before, and continued after, cassiterite. However, there are many areas of nearly barren pyrite, thus indicating that cassiterite deposition was not nearly so extensive as pyrite and quartz deposition; cassiterite and later pyrite mineralization took place along more localized zones.

Kozlowski and Jaskolski [11] in addition to stages equivalent to the early and late stages here described, recognized an earlier higher temperature stage characterized by tourmaline. However, the writer regards the development of tourmaline as being more closely related to rock alteration than to vein mineralization because of the widespread occurrence of tourmaline away from the veins in rocks of the Itos section and in the rocks of the lower levels of the other sections, and the scarcity of tourmaline in the vein filling.

(*b*) *Late Stage.* The important minerals listed in their order of abundance in the ore now being mined are jamesonite (or zinkenite), tetrahedrite (freibergite), galena, franckeite, andorite, bournonite, and stannite. The other primary minerals from the list of minerals reported from the Oruro veins are present in negligible amounts in the ore mined at present, although it is possible that they were present in appreciable amounts in the bonanza ore-shoots that were mined at earlier times. The chief source of silver in the ore is freibergite and andorite; but the minerals jamesonite, galena, and bournonite carry some silver, as

[11] Kozlowski, R., and Jaskolski, S.: op. cit., p. 63.

has been proved by assays of individual specimens of these minerals. Since some of the minerals of this stage look much alike, it is difficult to estimate the amount of each present in the ore; the following percentage estimate must be regarded as very approximate: jamesonite 67, tetrahedrite 13, galena, 4, franckeite 4, andorite 2, bournonite 2, stannite 2, all other sulphide minerals 6 per cent. It is estimated that the volume of vein material deposited during the late stage is about half of that deposited during the early stage.

Replacement of wall rock or older vein minerals was much less predominant during this stage than during the early stage; it is estimated that only about 35 per cent of late stage material was deposited by replacement of earlier minerals and wall rocks, the remainder being deposited by filling of open spaces.

The order of deposition of the common late-stage minerals as determined by Chace [12] is stannite, freibergite, bournonite, andorite, galena, and franckeite.

Although slickensided vein material suggests that minor structural adjustments took place along the fractures from time to time during vein formation, the two stages of mineralization were separated by a distinct structural break. The late-stage mineralization took place after a reopening of the fractures occupied by early-stage minerals. This conclusion is based on the following evidence: there has been extensive brecciation of the early minerals; the reopened fractures do not always correspond with the earlier fractures that have been filled and sealed with the pyritic ore of the early stage. Fractures occupied by late-stage minerals are sometimes found at one side of the early-stage veins. At other times late-stage veins are separated from the early pyrite-cassiterite vein by a horse of waste.

Zoning.—In the district as a whole lead-silver mineralization (later late-stage) is the most widespread areally although the total amount of vein material deposited was not great. In the mines themselves the quartz-pyrite mineralization is the most widespread.

[12] Chace, F. M.: op. cit., p. 89.

The silver and tin ore occurs as shoots defined by assay limits in the more extensive pyritic veins.

The late-stage (chiefly silver) mineralization is more extensive horizontally and vertically than the tin mineralization (early stage). Veins of argentiferous galena are known on the surface outside of the area occupied by the tin veins. In places, the San Luis and San José veins may be followed along the strike away from productive ore-shoots comparatively high in both tin and silver, to stringers that contain a little silver and no tin. Available data indicates that the ore of the lower levels, in general below the —300 m level, was mined chiefly for its silver content.

It is thought that the wider distribution of silver-bearing minerals occurred because the silver mineralization took place at a lower temperature than the tin mineralization. In the earlier stages of the silver mineralization, deposition persisted laterally farther from the center of influx of the ore-forming solutions than did the tin deposition. This was because the lower temperature silver-bearing solutions were not so sensitive to decreasing temperature as the high temperature tin-bearing solutions. During the later stages of the silver mineralization as the temperature receded downward, the silver could be deposited deeper and deposition persisted to greater depths than did the tin deposition.

Oxidation.—The silver has been leached from the outcrops so that the oxidized ores being mined at present are worked entirely for their tin content.

The major veins have been oxidized to as much as 150 meters vertically below the outcrop. Minor veins, which are narrower and more compact, in places are not oxidized more than 25 m below the outcrop. The veins are oxidized deeper than the wall rock.

The minerals of the oxide zone are limonite, quartz and chalcedony, jarosite, cassiterite, and cerussite. Thoroughness of early silver mining near the surface has been such that it is difficult to get exact information about supergene silver enrichment but it is known that a zone of secondary enrichment did exist. During the

period the writer has been familiar with the deposits, no silver minerals have been identified in the oxide zone; but old miners say that silver chlorides were formerly mined near the surface. There has been a residual concentration of cassiterite caused by leaching of other constituents. It is possible that some secondary cassiterite has been formed by re-deposition of tin released by the breakdown of stannite and franckeite.

Origin of the Deposits.

Source of the Ore-Forming Fluids.—The deposits are directly related to the quartz monzonite porphyry. The intrusion and solidification of the quartz monzonite porphyry bodies are thought to have caused the formation of the vein fractures. The ore-forming fluids came from the same magma body whose upper part terminates in the quartz monzonite porphyry outcrops. This view is held because the tin-silver veins are systematically arranged in older rocks near small quartz monzonite stocks, and because no productive tin veins are known to occur in the quartz monzonite.

Temperature of Formation.—Tourmaline, which is widely developed in some parts of the mine, especially in the lower levels, is indicative of high temperature. However, since it is rare in the vein filling, and its occurrence is considered to result from pre-mineral wall rock alteration, its presence may not indicate the temperature existing at the time the vein minerals were formed. It is probable that vein mineralization took place at somewhat lower temperature than is required for the formation of tourmaline.

The early-stage mineralization is known to have taken place at a higher temperature than the late stage, as is indicated by the minerals, and the fact that replacement of wall rock was more intense in the early than in the late stage. Cassiterite is formed chiefly at high or relatively high temperatures.[13] For this reason the quartz-pyrite-cassiterite mineral assemblage of the early stage mineralization is thought to have been formed at relatively high

[13] Ferguson, H. G., and Bateman, A. M.: Geologic features of tin deposits. ECON. GEOL., 7: 209–262, 1912.

temperatures. The walls of veins or stringers occupied exclusively by early-stage minerals tend to show a gradation from vein material to wall rock; this is not true of fractures occupied exclusively by late-stage minerals. According to Lindgren [14] temperatures of formation of the group of minerals of which the second stage minerals are members may have ranged from 175° to 300° C.

Depth of Formation.—Direct topographic evidence as to the depth at which mineralization took place is lacking. The maximum relief in the district is nearly 300 meters; so it seems likely that at least 300 m of rock has been eroded since the formation of the deposits.

Geologic evidence is present but its exact interpretation is more or less a matter of opinion. The explosive breccia bodies in the mines have their maximum development relatively near the surface; below the —200 m level there is less explosive breccia than on the —50 m level. The fracturing is complex near the surface and below the —200 m level it is relatively simple, but on the —300 m level the main veins have only a few branches. At the surface along some of the major veins there are large bodies of brecciated wall rock that have been mineralized; on the lower levels mineralized breccia is unknown. The grade of tin in the major veins begins to decrease markedly at about the —200 m level. All this evidence indicates that mineralization took place relatively near the surface.

Since all of the changes noted take place within about 300 m of the highest vein outcrop, it seems reasonable to estimate that the mineral matter of the present vein outcrops was deposited at a depth of around 1,000 to 2,000 feet.

Previous estimates of depth of formation were: as little as 1,000 feet by Lindgren; [15] and 1,000 to 4,000 feet by Chace.[16]

Classification of the Deposits.—Lindgren [17] has classified the Oruro veins as mesothermal. If the classification is based on

[14] Lindgren, W.: Mineral Deposits, pp. 529–530, 4th edit., 1933.
[15] Lindgren, W., and Abbott, A. C.: op. cit.
[16] Chace, F. M.: op. cit., p. 117.
[17] Lindgren, W.: op. cit., pp. 579–580.

mineral association alone, the veins properly belong in this group. If Graton's modification of Lindgren's zones [18] is considered, the early stage quartz-pyrite-cassiterite mineralization would be classed as mesothermal, whereas late stage sulpho-salt mineralization would be classed as leptothermal. If classified on the basis of depth alone, the veins would fall in the epithermal group.

Buddington [19] has given the name "xenothermal" to veins in which high temperature mineral associations are found relatively near the surface, *i.e.*, at a depth of 2,000 to 3,000 feet, and at a temperature of 300° to 500° C. In view of the relatively high temperature mineral association in the Oruro veins and the shallow depth at which they formed, it is the opinion of the writer that the veins should be classed as xenothermal.

PRACTICAL CONSIDERATIONS.

Distribution of Tin and Silver.—There is a myth around old mining camps that ore mined long ago must have been very high grade. Some of it undoubtedly was but certainly not all of it. There is evidence in the Oruro mines that some of the old stopes were mined on ore that cannot be worked at a profit under present conditions. It is probable that low-grade ore from such stopes was mixed with higher grade ore from other parts of the mine so as to increase the tonnage milled.

Since the upper parts of the major veins were mined out long ago, it is difficult to determine the location of the horizons of highest grade tin and silver ore. It is probable that the silver ore was more consistent in grade throughout the vertical range exposed by mining than was the tin ore. High-grade silver ore from the lower levels does not necessarily indicate that the silver content increases with depth because not enough is known about the silver content of the ore mined earlier from the higher levels. It is the writer's opinion that the silver content of the ore did not

[18] Graton, L. C.: The hydrothermal depth-zones. Ore Deposits of the Western States, Lindgren Volume, A. I. M. E., pp. 186–189. 1933.

[19] Buddington, A. F.: High temperature mineral associations at shallow to moderate depths. ECON. GEOL., 30: 205–222, 1935.

increase with depth throughout the mine area as a whole. The tin content of some of the minor veins suggests that rapid deposition took place in them near the surface; it is possible that the same thing occurred in the major veins. In them the most productive zone was from the zero to the —100 m level.

When the veins are followed downward it is found that the tin content decreases sooner and more sharply than does the silver content. In the veins that have been worked and explored extensively below the —200 m level (San Luis, Grande, Bronce, and Purisima) it was found that the tin content began to decrease sharply at a higher level than the corresponding decrease of the silver content. In the San José vein, DeWijs [20] found that the tin content dropped rather sharply below the —100 m level (elevation 3,700 m) but the corresponding decrease in the silver content was at the —150 m level (elevation 3,650 m).

It is known that ore from the lower levels of the Grande vein, between the —200 m and —290 m levels, was mined primarily for its silver content. The few data still available from the lower levels of the San Luis and Purisima veins indicates that those ores were also mined chiefly for the silver they contained. The lower levels of these veins were mined a number of years ago and the workings are now flooded. The deeper veins carry tin to greater depths, for example, the Bronce and San Luis veins have been worked deeper than any other of the major veins. In these two veins good tin ore extended downward farther than in veins that were not worked so deep.

The ore-shoots of all parts of the mine are laterally defined by assay limits; bodies of workable ore can be followed along the strike into ore too low grade to be worked under present conditions.

In general it can be said that silver ore is more persistent laterally and vertically than the tin ore. Deposition of tin seems to have been more closely controlled by depth than silver deposition, probably because the higher-temperature, tin-bearing solutions

[20] DeWijs, H. J.: Private Report to Cia. Minera de Oruro, 1937.

were more sensitive to decrease of temperature as they spread out laterally or approached the surface.

There are numerous minor veins that were worked near the surface for their tin; many contain no silver-bearing minerals. Where veins of this type have been cut from 50 to 100 m below their outcrop, they were barren but veins containing appreciable silver-bearing minerals show a lesser tendency to become barren abruptly at such shallow depth. In general, veins of this type occur on the hanging wall side of the major veins. Such veins indicate that part of the tin mineralization must have been closely controlled by depth. It is thought that at the beginning of tin mineralization rapid deposition occurred as the solutions neared the surface. As tin mineralization continued, the temperature of the ore-forming solutions decreased enough to permit deposition at increasing depth. During this time some of the minor fractures encountered by the first solutions became closed, and no further deposition could occur.

Depth of Ore.—It is estimated that the lower limit of ore mineable under present conditions is about the —360 m level (elevation 3,440 m), 460 meters below the average elevation of the higher outcrops. This figure is arrived at by weighting the veins according to their importance, which of course can be only approximate, especially since the lower levels have been flooded for a number of years.

Favorable Areas for Future Prospecting.—Although several possibilities worthy of exploration exist in the immediate vicinity of the mines, the most favorable areas for prospecting are in the outlying parts of the hills in areas of older rocks near quartz monzonite porphyry intrusives. Since such areas are for the most part covered by alluvial deposits, geophysical prospecting will be necessary to localize favorable spots so that some more exact method of prospecting can be efficiently used. The gravels of several of the canyons should be prospected for tin placers, just below the Pleistocene lake level.

ACKNOWLEDGMENTS.

The writer wishes to thank Mr. W. V. DeCamp, General Manager of Mines, Mauricio Hochschild, S. A. M. I. for permission to publish this paper. Grateful acknowledgment is due Professors H. Ries and C. M. Nevin of Cornell University for reading of the manuscript.

COMPAÑIA MINERA DE ORURO,
ORURO, BOLIVIA,
July 2, 1941.

MINOR CONSTITUENTS IN SPODUMENE.[1]

ALTON GABRIEL, MORRIS SLAVIN AND H. F. CARL.

ABSTRACT.

Spodumenes of high purity were examined spectrographically for minor impurities. Eleven samples from eight localities showed iron, manganese, titanium, gallium, sodium and potassium in all samples, tin in nine samples and rubidium in one. X-ray and petrographic studies show that the impurities are present in the spodumene itself, probably as isomorphous replacements. The iron and other objectionable impurities may be present in some spodumenes to such an extent as to limit their use in the ceramic field.

The X-ray powder diffraction pattern for spodumene is given.

SPODUMENE, $LiAl(SiO_3)_2$, the lithium-bearing pyroxene, is commonly associated with quartz, feldspar, micas, and minor accessory minerals in granitic pegmatites. The theoretical Li_2O content is 8.4 per cent, although published analyses show a content generally lower than this value.

The promise of utilization of spodumene for ceramic and chemical purposes has been considerably enhanced in recent years by development of methods of beneficiation. Hitherto, only high-grade deposits, or deposits containing large crystals that could be hand-picked, were worked, but now lower grade material of finer crystal size can be treated. Fraas and Ralston[2] showed that spodumene could be concentrated by a process of decrepitation. Norman and Gieseke[3] and others[4] accomplished the beneficiation by froth flotation.

The most promising ceramic uses of spodumene are for purposes where color—or rather the absence of color—may be im-

[1] Published by permission of the Director, Bureau of Mines, U. S. Department of the Interior.

[2] Fraas, Foster, and Ralston, O. C.: Beneficiation of spodumene by decrepitation. U. S. Bur. Mines R. I. 3336, pp. 13, 1937.

[3] Norman, James, and Gieseke, E. W.: Beneficiation of spodumene rock by froth flotation. A. I. M. E., Tech. Pub. 1161, Mining Technology, April 1940.

[4] U. S. Bur. Mines, Minerals Yearbook, p. 1475, 1939.

portant. For instance, Boyd[5] suggests its use as an admix with feldspar to lower the maturing temperature of whiteware bodies and glazes. It may be a desirable constituent in glass.[3] Therefore, the chemical impurities, particularly the tinting elements such as iron, must be below certain limiting values in order that the uses of spodumene be not limited on this score.

Analyses. A survey of published analyses of the mineral shows an iron content appreciably greater than that contained in commercial feldspar. Mellor[6] presents a series of analyses with an average value of 1.36 per cent Fe_2O_3, and Dana[7] records a series of twelve samples, eleven of which had iron contents ranging from 0.20 to 2.73 per cent Fe_2O_3. Boyd, for the work mentioned above, used a spodumene containing 0.19 per cent Fe_2O_3. Schwartz and Leonard[8] found 0.53 per cent Fe_2O_3 and 6.78 per cent Li_2O in a selected large crystal from the Black Hills district of South Dakota. Wild and Klemm[9] by a qualitative spectrographic method observed the presence of iron and manganese in all samples they tested. A colorless spodumene showed iron and traces of tin, cobalt, and sodium. A clear kunzite, one of the gem varieties of spodumene, contained only small quantities of iron. They concluded that yellow tints are due to high iron. Petrographic examination by the senior author of the flotation concentrates prepared by Norman and Gieseke[3] showed extraneous iron and manganese as oxide films coating some of the grains of spodumene, and speck iron oxides and mica not completely removed by flotation. Observation on other samples indicated that the facile explanation of ascribing the relatively high iron content exclusively to extraneous impurities was not the complete story.

[5] Boyd, J. E., Jr.: Pyrometric properties of spodumene-feldspar mixtures. Jour. Amer. Cer. Soc., *21*: 385–8, 1938.

[6] Mellor, J. W.: A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. 2. Longmans Green & Co., London, 1927, p. 425.

[7] Dana, E. S.: A System of Mineralogy, 6th Edit. John Wiley & Sons, New York, 1920, p. 367.

[8] Schwartz, G. M., and Leonard, R. J.: Alterations of spodumene in the Etta Mine, Black Hills, S. D. Amer. Jour. Sci. *11*: 257–64, 1926.

[9] Wild, G. O., and Klemm, R.: Mitteillungen über Spektroskopische Untersuchungen an Mineralien V. Spodumen. Centr. Min. Geol. 1925A: 324–6.

Accordingly, work was undertaken to provide a definite answer to the question: What is the nature and concentration of the impurities in spodumene that cannot be removed by mechanical methods? This, it will be recognized, is the old problem of determining whether a minor element occurs as a constituent in a mineral or is present as a separate phase.

Preparation of Samples.—The suite of samples upon which the work was done represents a geographic range, and included some of the best-known spodumene deposits. The samples were crushed to about minus-4-mesh and placed under a binocular microscope. This grain size was small enough to be transparent, so that inclusions could be seen. The clearest, freshest grains, free of extraneous specks, were selected, removed from the stage with bone-tipped tweezers, crushed further in an agate mortar, and finally examined petrographically for impurities. The samples thus prepared comprised the material for analysis.

Spectrographic Results.—The analytical method employed was a spectrochemical procedure developed by one of the authors [10] during the past five years, and particularly applicable to the determination of minor constituents in silicate rocks. The spectrographic method had two distinct advantages for the present problem, as only a small sample is required and as there is very little possibility of overlooking metallic elements present in low concentrations. Selecting individual small grains is an extremely tedious and painstaking job, and such a procedure would be practicable only for small quantities of material. The samples weighed about 200 milligrams each; nevertheless, this was sufficient to run all analyses in duplicate, and in several regions of the spectrum and for X-ray and petrographic studies. The spectrograph employed was of large dispersion, and the principal lines of all the elements looked for could not be covered by one wavelength setting.

[10] Slavin, Morris: Quantitative analysis based on spectral energy. Ind. & Eng. Chem., Anal. Ed., 10: 407–411, 1938. Iron arc as a standard source for spectrochemical analysis. Ibid. 12: 131–133, 1940. Spectrochemical analysis of glass sand. Glass Indus., 22: 341–3, 1941.

As to the probable accuracy to be expected, repeated tests of the general procedure, and comparisons with analyses obtained by chemical methods indicate an average error between 5 and 10 per cent of the amount present. There is no reason to suppose that the present results deviate from this value, since no unusual experimental difficulties were encountered.

The analytical results are given in Table I.

TABLE I.

SPECTROGRAPHIC ANALYSIS OF MINOR CONSTITUENTS IN SPODUMENE.

Sample No.	Origin.	Per cent.							
		Fe_2O_3	MnO	TiO_2	SnO_2	Ga_2O_3	Na_2O	K_2O	Rb_2O
1	Lincolnton, N. C.	0.44	0.54	0.012	0.15	0.07	0.33	0.34	0.048
2	Dixon, N. M.	0.040	0.013	0.004	n.d.*	0.08	0.27	0.051	n.d.
3	Kings Mt., N. C.	0.30	0.076	0.006	0.065	0.050	0.27	0.021	n.d.
4	Kings Mt., N. C.	0.41	0.055	0.004	0.063	0.064	0.28	Tr.	n.d.
5	Tinton, S. D.	0.17	0.014	0.004	0.062	0.032	0.48	0.37	n.d.
6	Warren, Me.	0.69	0.074	0.005	0.084	0.058	0.29	0.32	n.d.
7	Warren, Me.	0.73	0.082	0.011	0.12	0.054	0.26	0.12	n.d.
8	Grover, N. C.	0.78	0.059	0.010	0.076	0.056	0.27	Tr.	n.d.
9	Grover, N. C.	0.64	0.024	0.010	0.079	0.081	0.27	Tr.	n.d.
10	Keystone, S. D.	0.30	0.021	0.004	0.047	0.042	0.35	0.10	n.d.
11	Pala, Cal. (Kunzite)	0.020	0.073	0.003	n.d.	0.043	0.26	0.022	n.d.

* = not detected.

The determination of Li_2O was also attempted spectrographically but proved difficult in the range of concentrations contained in spodumene. The difficulty lay in the very limited choice of lines, due to the extremely simple spectrum of lithium and to the denseness of the lines obtained. However, it was quite possible to make a close estimate by a visual comparison with synthetic standards photographed on the same plate with the unknowns. The lithia content of all the samples fell between 6.5 and 7.5 per cent Li_2O.

Calcium and magnesium were present as traces, but were not quantitatively determined. Faint lines of chromium were noted occasionally but were not consistently present even in duplicates of the same sample. As the limit of chromium detection is approximately 0.001 per cent, its content is of about this order.

With the exception of the kunzite (No. 11), which was lilac-colored, the spodumenes were colorless, slightly grayish, or slightly greenish. Petrographic examination of the selected samples showed normal spodumene in all cases. Samples 1, 2 and 3 showed some elongated bubbles (probably trapped air) and some very fine films of inclusions along cleavage planes. Samples 5, 6, 9, and 10 contained bubbles, some oriented films, and minor alteration cracks along cleavage planes, which imparted a slight cloudiness to the spodumene grains. Samples 4, 8, and 11 were very pure specimens, being near gem variety. They were essentially free of bubbles, films or alteration.

The results show that iron and other impurities may be so intimately associated with spodumene as to be incapable of removal by mechanical means. Samples 4 and 8 are among the purest of the suite, yet the iron content is appreciable, suggesting that the minor constituents may be present as solid solutions or isomorphous replacements in the spodumene itself. Samples 1, 2, 3, 4 were known to have been obtained in fresh material from locations below the weathered zone.

That the spodumene contained no acid-soluble iron was shown by the following experiment. An additional batch of grains was selected from crude sample 3 and was finely ground. One portion of the sample was reserved, the other was boiled for an hour in concentrated hydrochloric acid and then washed repeatedly with distilled water. The two portions were analyzed in duplicate for their iron content, with the following results: Untreated sample—0.28, 0.30 per cent Fe_2O_3; leached sample—0.29, 0.29 per cent Fe_2O_3.

The small tin content of some of the spodumenes is of interest. Cassiterite is found in the vicinity of many spodumene-bearing pegmatites. According to Hess,[11] the tin deposits of the Carolinas follow the same line as the spodumene pegmatites. Cassiterite was not observed in any of the selected grains. Wild and Klemm[9] noted the presence of tin in some spodumenes.

[11] Hess, F. L.: Lithium in North Carolina. Eng. and Min. Jour. 137: 339–342, 1936.

Papish and Holt [12] found gallium to be a constituent of many minerals, which included spodumene, clays, bauxites, feldspars and other aluminum-bearing silicates. Lepidolite, the lithium bearing mica, contained sufficient gallium to make possible an extraction by chemical methods. The gallium content of the spodumenes reported herein is appreciably higher than the amounts observed by Papish and Holt. Wild and Klemm [9] noted strong lines of gallium in the spectrum of kunzite.

Spodumene is a member of the monoclinic group of pyroxenes. Warren and Biscoe [13] ascribed the general formula $X_mY_{2-m}(Si, Al)_2(O, OH, F)_6$ to this group where X can be Ca, Na, K, Mn, while Y can be Mg, Fe, Al, Ti, Mn, Li. "M" tends to be either 1.0 or 0 but may have intermediate value, as illustrated particularly in the case of augite. Under these conditions where numerous replacements are possible it is not unexpected to find the elements in spodumene reported in Table I.

X-Ray and Petrographic Examination. Certain samples were selected for X-ray examination and for a more extended petrography study than was accorded the other members of the series. The selection was made to include sample 11, which had the lowest impurity value; sample 8, which had the highest iron content; sample 3, with intermediate impurity value; and sample 1, which was relatively high in both iron and manganese.

The petrographic results showed that all samples showed refractive indices $\alpha = 1.660 \pm .001$ and $\gamma = 1.675 \pm .001$ and a maximum extinction angle $Z \wedge c$ of $+25°$. No significant differences could be detected.

The X-ray powder diffraction patterns also showed no detectable variation from sample to sample. Measurements of the patterns gave identical interplaner spacings, d_{hkl}, well within the limit of error of the measurements. No evidence was found of a general displacement toward the origin of one sample as compared to another, nor were any of the $K\alpha$ doublets at high angles

[12] Papish, Jacob, and Holt, D. A.: Gallium. Jour. Phys. Chem., 32: 142–147, 1928.

[13] Warren, B. E., and Biscoe, J.: The crystal structure of the monoclinic pyroxenes. Zeit. Krist. 80: 391–401, 1931.

of diffraction, up to 80°, shifted relative to one another. Hence, neither the presence of a solid solution nor any change in the axial ratios of the unit cell was indicated. That such a change in axial ratios might be expected due to low concentrations of impurities has been shown by Rooksby and Partridge [14] and by Posnjak and Greig.[15] The former obtained powder patterns of mullites which showed considerable shifts in the doublets at high diffraction angles caused by very small percentages of either Fe_2O_3 or TiO_2, and both obtained a general expansion of the lattice when larger percentages of impurities were present.

The X-ray examination supports the general conclusion that the impurities in spodumenes are present as isomorphous replacements and indicates that they are not present in solid solution or in such a manner as to distort or expand the unit cell.

The data on the X-ray powder diffraction pattern of spodumene from complete measurements of three of the four samples examined are given in Table II.

The patterns were obtained on a G.E. "XRD" camera, radius 7.19 cm, with a divided septum and slit system. The camera allowed diffraction lines to be registered on both sides of the undeviated beam between 5° and 168°, or up to an angle of diffraction, θ, equal to 84°. The patterns of two samples were recorded together on the same film, thereby permitting accurate direct comparison and eliminating possible differences arising from different films. Each film was calibrated by the addition of a small percentage of cp sodium chloride to one of the spodumenes. The samples, mounted in thin-walled capillary tubes, were rotated about the axis of the camera at one rpm during the one hour exposure time. Copper Kα radiation, $\lambda = 1.537$A°, filtered through nickel foil was used. The tube was operated at 30 KV and 20 ma. The patterns were measured on a ruler with scale and vernier reading to 0.10 mm. Duplicate readings on the same lines usually checked within this amount.

[14] Rooksby, H. P., and Partridge, J. H.: An X-ray study of natural and artificial mullites. Jour. Soc. Glass Tech., *23*: 338–346, 1936.

[15] Posnjak, E., and Greig, J. W.: Notes on the X-ray diffraction patterns of mullite. Jour. Amer. Cer. Soc., 16: 569–583, 1933.

TABLE II.

X-RAY POWDER DIFFRACTION PATTERN OF α SPODUMENE.

I	dhkl	I	dhkl	I	dhkl
3	6.09	1/2d?	1.489	1/2+	.982
5	4.365		1.477	1/2+	.972
6	4.195	4	1.457	1/2	.964
4	3.435	1/2	1.415	1	.952
4	3.180	2	1.394	1/2−	.944
1/2−	3.030	2	1.356	1/2+ α_1 α_2	.938
10	2.915	1d?	1.341		
1	2.855		1.335	1/2	.931
8	2.785	4s	1.328	1/2	.920
1b	2.658	4b	1.312	1/2	.912
1	2.545	1/2	1.299	1/2+	.897
6	2.445	1b	1.285	1/2	.889
2	2.345	1/2+	1.273	1/2−	.885
1/2	2.214	1s	1.251	1/2−	.880
1/2−	2.174	1/2−	1.239	1/2	.8735
1/2+	2.136	1/2	1.232	1/2	.8705
4	2.104	1/2+	1.224	1/2+ α_1 α_2	.8675
2	2.054	4	1.211		
1	2.024	1/2	1.185	1/2	.8615
2	1.924	2	1.167	1/2	.8380
4	1.858	1/2?	1.157	1 α_1 α_2	.8355
1/2s	1.840	1/2d?	1.128		
1/2	1.820		1.123	1/2	.8310
1/2b	1.783	1/2	1.087	1/2	.8265
1	1.734	1/2	1.076	1/2	.8215
1/2	1.715	1/2	1.052	1 α_1 α_2	.8205
1/2−	1.680	1	1.039		
1/2−	1.663	1	1.028	1/2	.8170
1/2	1.644	1/2	1.014	1/2?	.8152
6	1.603	1 α_1 α_2	1.010	1/2	.8077
1/2	1.590			1/2	.8025
7	1.565	1/2	1.003	3	.7925
3	1.520	1/2	.992	1/2	.7885
		1/2	.987	2b	.7837
				2b	.7814

b = broad.
s = sharp.
α_1 / α_2 = superimposed α_2 of one line on α_1 of the next.
d? = probably a poorly resolved doublet.

The relative intensities of the lines were obtained from visual estimations of the relative densities of the lines above the background. Because of the numerous faint lines in the pattern, the estimate of intensities $1/2 \pm$ is given merely to indicate the densities of these lines relative to other faint lines nearby. The numerous faint lines close together made if difficult to distinguish

between the overlapping α_1 and α_2 lines in certain regions. Where it was not possible to distinguish both $K\alpha$ doublets such faint lines have been either omitted from the table or indicated by a question mark.

The near-gem varieties of spodumene that were selected for this study should not be considered as representative of the spodumene deposit as a whole. It is conceivable that the non-gem varieties in the deposit may contain less impurities than the essentially clear grains that were analyzed. The fact that Boyd [5] found 0.19 per cent Fe_2O_3 as the iron content of material from a deposit where the authors found 0.30 per cent Fe_2O_3 in selected grains, indicates that a variation in the minor constituent values may be expected.

CONCLUSIONS.

The examination of eleven samples of spodumene from eight localities, using selected material, showed iron, manganese, titanium, gallium, sodium, and potassium in all samples, tin in nine samples, and rubidium in one.

The combined data collected show that impurities can occur in the spodumene itself and suggest that the impurities exist as isomorphous replacements in the spodumene structure.

Potentially commercial deposits of spodumene should be examined closely for the objectionable minor constituents for they may occur as constituents in the spodumene itself, or as films in cleavage planes and therefore not separable from the spodumene by mechanical processes. These "unavailable" impurities may be sufficiently high in some deposits as to limit their use in the ceramic field. The near-gem varieties of spodumene reported herein should not be considered representative of the spodumene deposit as a whole, as the non-gem varieties may conceivably contain less impurities than the essentially clear grains analyzed.

The X-ray powder diffraction pattern for spodumene is given.

ACKNOWLEDGMENTS.

The authors are indebted to Mr. Oliver C. Ralston, Chief, Nonmetals Division, Federal Bureau of Mines, for critical review of the manuscript and for the donation of certain of the spodumenes used, and to Mr. Frank L. Hess, principal mineralogist, Federal Bureau of Mines, for the use of samples that he collected in the field.

BUREAU OF MINES,
EASTERN EXPERIMENT STATION,
NONMETALS DIVISION, COLLEGE PARK, MD.,
January 5, 1941.

A NATIVE COPPER DEPOSIT NEAR JEFFERSON CITY, MONTANA.

J. D. FORRESTER.

ABSTRACT.

Native copper occurs as a cement placer material within a restricted area near Jefferson City, Montana. The deposit is situated in a shallow canyon near the headwaters of the major Prickly Pear Creek drainage system where an intimate association of peat muck, bog-iron oxide, and alluvial gravels combine to establish a unique set of natural reducing conditions that attend the resulting deposition of secondary copper from percolating sub-surface waters. The copper is derived by oxidation of narrow epigenetic veins that occur up-stream in rocks of the Boulder batholith. It is carried downward as copper sulphate in solution until it reaches the reducing environment.

Although both carbonaceous peat muck and iron oxide may be reducing agents, it appears that, in this instance, the iron oxide deposit plays the dominant role in reduction. The peat muck, in fact, seems to have even kept the copper in solution in most cases, and thus has permitted its localization on or near the limonitic bog material.

FOREWORD.

This occurrence of a native copper accumulation was first called to the writer's attention by the owner of the property, Mr. C. J. O'Connell of Jefferson City, Montana. In view of the high concentration of native copper in specimens which were presented by O'Connell, together with the possibilities offered to determine the primary source of the copper and the manner of deposition in this secondary native form, a detailed field study and analysis was made in the summer of 1939. The present paper is a summary of the results of the examination.

For interest, assistance, and for permission to publish the results of the study, the writer is indebted to Mr. O'Connell. Messrs. R. H. Sales and M. H. Gidel, of the Anaconda Copper Mining Company, graciously have released information acquired by the author

when in their employ. In addition, Mr. Gidel has offered certain suggestions and observations he has made during subsequent visits to the area, the value of which is hereby acknowledged. Thanks are also due Dr. W. H. Cone of the University of Idaho, who aided in the gathering of laboratory data.

LOCATION.

The area is located in a small gulch, 3.5 miles southwest of Jefferson City, Jefferson County, Montana. It is in Sections 23 and 24, T 7 N, R 4 W, Montana Principal Meridian, and is near, if not actually adjoining, the famous highly-mineralized Corbin-Wickes mining region. The gulch, known locally as Copper Gulch, is tributary to Beavertown Creek which is, in turn, a headwater member of the major Prickly Pear Creek drainage system. The main physiographic feature of the immediate area is an open, easterly trending canyon (Copper Gulch) delimited by steep but relatively low side hills on the north and south. Surface water is intermittent and negligible. Surface and sub-surface drainage is from west to east.

DEVELOPMENT.

Mr. O'Connell became interested in the area as a boy, after a group of gold prospectors had abandoned several tunnels that they had driven (prior to 1870) in the gravels of Copper Gulch, when the nuggets found proved to be native copper. The inaccessible tunnels exceed 1,000 feet in length (Fig. 1). Other later pits and tunnels have exposed small vein outcrops on the canyon slopes and one tunnel has penetrated several hundred feet into rather barren granite. The American Smelting and Refining Company reputedly obtained iron flux from the area for their East Helena Smelter in 1886–1887.

The most recent development has been by O'Connell in search of sub-surface copper-bearing waters and gravels. In 1937, he sunk the Windlass Shaft in the bed of the gulch and encountered

appreciable quantities of "flour" copper and one specimen of cuprite. Since that time he has made several openings near or on the floor of the gulch. Fig. 2 illustrates (as of July 5, 1940) the amount and manner of his current work.

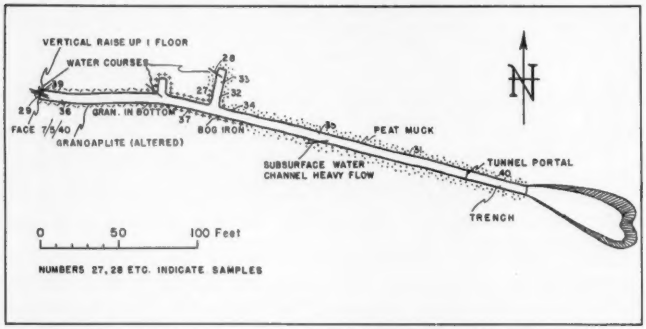

FIG. 1. Geologic map native copper deposit near Jefferson City, Montana.

GENERAL GEOLOGY.

The region lies within the Boulder batholith of southwestern Montana, and the country rocks, where exposed on the hill slopes, are granites (quartz monzonites) and aplites, or their various gradational phases. Above the native copper occurrence are several northeasterly striking zones of small veins (6 inches to 16 inches in width) and stock-works in aplitic phases of granite, which trend obliquely across the area. They contain, in addition to quartz, oxidized compounds of iron and manganese oxides, with minor copper carbonates.

Extensive sand and gravel deposits cover portions of the lower hill slopes, and parts of the stream channel area. They are heterogeneous masses that appear to have formed as outwash and alluvial fans from the adjacent hills during periods of torrential rains.

Spring or bog-iron oxide deposits were formed over portions of the surface, and particularly over part of the lower creek area,

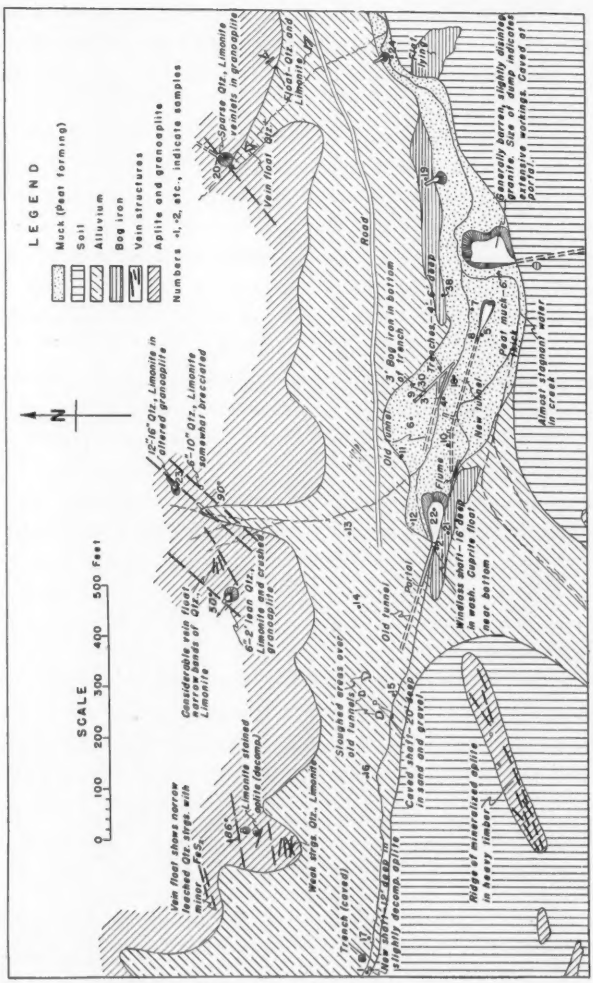

FIG. 2. New tunnel, native copper deposit. For relative position see Fig. 1.

prior to, and possibly to some degree intermittently with the development of the alluvial fans. Erosion and deposition were such that this accumulation extended entirely across the stream channel, and thereby constituted a reef or dam to the flow of water that subsequently developed.

The damming and temporary base-leveling of the creek led to the formation of a peat swamp, west of the iron reef. It is approximately 125,000 square feet in area and has an average depth of from ten to fifteen feet. Surface waters now have breached the natural dam, and incised the flat-lying iron oxide strata. The meandering character of the present stream channels within the peat swamp area is in marked contrast to the relatively straight stream course above and below this locality.

Native copper occurs in appreciable amounts, but in apparently spotty localizations within the peat muck and gravel strata. This copper has been, and is probably even now being obtained by the oxidation and leaching of the narrow veins and stockworks. The copper-iron sulphate bearing waters have percolated down stream (easterly) through the permeable soil and alluvium mantle within the catchment basin. Upon reaching the peat deposit and iron reef locality, where conditions of flow were retarded somewhat, the copper-laden waters have been reduced and native copper has been precipitated.

Favorable conditions for transportation and deposition have not prevailed throughout the entire swamp area, however, since the copper apparently is localized to certain limited channelways where it has formed as a cement or coating on twigs, matted fungus, and grass roots, and as scale or nuggets on gravel and bog-iron boulders.

FIELD TESTS AND DATA.

The later development work has not exposed the strongly greenish-yellow waters observed by O'Connell, about 1882, to be issuing from the old tunnels. However, his panning of portions of the peat and associated materials, revealed in places native copper

"colors" and nuggets. It is possible that the highly contaminated waters may have been entirely drained from the swamp as a result of tapping their channels on bedrock by the old tunnels that were driven.

The location of samples taken during the field study are shown on Figs. 1 and 2. These included several auger-drill cores of muck and alluvium.

Series A Samples.

No.	Per Cent Cu.	Per Cent Fe.	Description.
1	0.0 *		Shallow shaft water diluted by surface flow.
2	0.0		Diluted shaft water.
3	0.0		Trench water.
4	0.0		Water rising from old tunnel.
5	0.090	14.96	Peat muck with copper carbonates at depth of 3 feet in bog-iron stratum.
6	0.060	9.53	Peat muck—14 inches depth.
7	0.0001		Water seep from creek bank—possibly some dilution.
8	0.0		Water seeping from floor of new tunnel.
9	8.340	4.11	Peat muck 2½ feet below surface.
10	0.020	3.19	Peat muck 4-foot auger hole.
11	0.015	0.89	Peat muck and sand mixed; 4 feet to water. No core from auger hole 4–6 feet.
12	0.0	2.87	Ten inches peat muck—12 inches bog-iron with gravel below. Auger hole—3 feet to water. No core 3–4½ feet.
13	0.0	1.69	Sand from 4 foot auger hole.
14	0.005	1.99	Sand and gravel—4-foot hole.
15	0.0	1.99	Sand with minor peat muck. Three-foot auger hole; rock on bottom.
16	0.0	1.19	Sand and gravel—4-foot auger hole.
17	0.005	2.39	Sand and gravel in upper 3.5 feet. Muck lower ½ foot in auger hole.
18	0.0	2.79	Peat muck—4-foot auger hole.
19	0.07	10.78	Bog-iron—10-foot in cut.
20	0.14		Quartz, limonite and manganese oxide veinlets on dump; leached and brecciated.
21	0.12	11.68	Bog-iron—4-feet exposed.
22	0.0	3.09	3½ foot auger hole in dump from shaft.
23	0.0		12–16 inch vein quartz and limonite in altered granoaplite.
24	0.0	2.19	Muck upper 3½ feet; sand and gravel 1 foot.
25	0.0	2.39	Muck upper 2 feet, sand lower 2 feet.
26	0.0	2.59	Mostly sand; some peat muck.

* The zero copper content in water and specimens does not necessarily mean its total absence; only that it is below the detectable limit of the assay method used for Series A. Exceedingly dilute solutions probably would yield appreciable copper for deposition by reduction over a long time.

Effort was made to avoid contamination in taking water and core samples, but it was impossible to obtain undiluted specimens in several instances. Samples of bottom shaft water were obtained by means of a quart bottle whose cap was released after immersion.

Supplementary analyses were also made of certain samples as follows:

No.	Fe.	S.	Au.	SO_3.	CaO.
7	Tr	Tr			87.7 ppm
19			0.006 oz	0.374%	0.420%
20			0.016 oz		
21			0.006 oz	0.415%	0.510%
23			0.005 oz		

Series B.

Another series of samples was placed in sealed glass containers for later laboratory tests by a potentiometer method. The potential of platinum electrodes placed in the water samples, or in a solution prepared by shaking the solid samples with distilled water, were compared with that of a platinum electrode placed in a very dilute copper sulphate solution (0.5 mg./ml.). Variations in potentials indicate whether copper will or will not be readily precipitated as native metal in or by the specimens. That is, if the sample exhibits a negative potential, then copper should, in this environment, be actively reduced to the metallic state. The degree of negative voltage registered by the specimen is a measure of its relative strength as a reducing medium. Those materials giving a positive voltage reaction are reducing agents only when the concentration of copper therein is greater than 0.5 mg./ml. When the copper concentration is less than 0.5 mg./ml., they would tend to keep the copper in solution in the percolating sub-surface waters. The results of the potentiometer tests are given below:

No.	Potential (Volts).	Approx. pH.	Copper by Iodide Method—	Description.
27	+0.045	4.0+	3.95 mg/100 cc	Rich copper-bearing quartz gravel and water from new tunnel.
28	+0.177	6.0	0.15 mg/100 cc	Water from crosscut, new tunnel; weak green tint.
29	−0.482	6.0	0.11 mg/100 cc	Water from face of new tunnel (strong H_2S or S smell).
30	−0.139			Iron reef material in original cut.
31	+0.170		0.03%	Moist peat muck, north wall of new tunnel.
32	+0.070			Moist peat muck and sand, east wall of crosscut.
33	−0.030	4.0		Moist bog-iron and peat muck; crosscut.
34	+0.030	4.0+		Sand cemented by minor iron oxide; some copper.
35	−0.127	6.0−		Copper-rich sand, iron oxide, and peat muck.
36	−0.073			Weathered granite bedrock, iron reef, and peat muck 28 ft below surface.
37	−0.077			Bog ore, wall of crosscut.
38	−0.100			Bog-iron reef material on surface.
39	−0.055	4.0		Granite and gravel from contact, with some iron oxide.
40	−0.065	4.0		Rich copper-bearing sand, new tunnel.

The presence of copper in solution in Series B is demonstrated by the copper content of the water specimens above listed. It appears that the more negative (less positive) the potential of the percolating waters, the less copper could be expected to be in solution.

Since the negative potentials exhibited by the iron oxide indicate that it is generally a relatively strong reducing agent, the negative water solution may have become a reducing medium through contact with the limonitic material.

INTERPRETATION OF FIELD AND LABORATORY DATA.

The field and laboratory data suggest that a rather unusual combination of natural conditions have prevailed in the area for the development of this particular native copper deposit. Subsurface, percolating waters have obtained copper sulphate released by oxidation of primary copper-iron sulphides contained in nar-

row veins and stockwork on the hill slopes of the drainage basin. These sulphate waters, upon reaching the site of deposition, encountered a reducing environment, and metallic copper has been precipitated as nuggets and as a cement and coating on twigs, matted roots, gravel, and bog-iron particles.

Clarke [1] cites several references that indicate copper may be precipitated by various reducing agents, among which are iron oxides and organic substances. Old mine timbers, impregnated with native copper particles, are often encountered in the mines at Butte, Montana, and other localities.

Lovering [2] has presented an interesting analysis of metallic copper precipitation and concludes that organic matter has been the agency of precipitation in the deposit near Cooke City, Montana, which he studied. However, the Cooke City occurrence differs from that at Jefferson City in that the native copper is confined to the black muck layers and does not occur in the associated gravel and sand strata.

In the Jefferson City deposit two of the common reducing agents of copper sulphate solutions occur in appreciable quantities and in close association, namely, bog-iron oxide and carbonaceous peat muck. The native copper is not confined strictly to the peat muck but is also present in associated gravels and iron oxide materials. The intimate occurrence of the two reducing agents is attributed to damming of the creek by an iron oxide reef, which resulted in local base-leveling and the development of attendant swampy conditions favorable for an accumulation of peat muck. The damming of the drainage has also had the effect of slowing up the migration of waters through the area and thus gives opportunity for a more complete removal of copper from the solutions low in copper content. This fact, together with the meager amount of surface water is probably the reason that such solutions have not been further diluted or washed down the creek, and why

[1] Clarke, F. W.: The data of geochemistry. U. S. Geol. Surv. Bull. 770, 5th Edit.: 670–672, 1924.

[2] Lovering, T. S.: Organic precipitation of metallic copper. U. S. Geol. Surv. Bull. 795: 45–52, 1927.

concentrations of the native metal were not found downstream from the reef.

Analyses of sample Series A and B further indicate that, although the copper occurs in only spotty localizations, the principal conditions in the depositional zone have been generally of a reducing character, as would be expected, but, however, that the activity of the organic matter (peat muck) in this respect is largely clouded or exceeded by the presence of more actively reducing bog-iron oxide. The dominant reducing material is bog-iron for it is relatively high in copper content and is still actively negative, in most instances. Peat may be an effective precipitant in some places, but the occurrence of copper in this deposit indicates that it has not been the dominant precipitant. The muck may have been an active reducing agent when organic decay was rapidly progressing but now, when decomposition has abated somewhat, it even has a positive potential, for the most part, and thus tends to keep some of the copper in solution and to concentrate the precipitation on or in close proximity to the negative bog-iron. That an oxidizing environment does now, at least, locally exist in some places is substantiated by the cuprite specimen found at depth in his shaft by O'Connell. The cuprite has the physical appearance of an oxidized product of a native copper nugget. Incidentally, some of the specimens taken by the writer appear to be weathering to oxide compounds since they were collected.

UNIVERSITY OF IDAHO,
MOSCOW, IDAHO,
Dec. 22, 1941.

GEOLOGY AND ORE DEPOSITS OF THE DILLON NICKEL PROSPECT, SOUTHWESTERN MONTANA.

HELEN SINKLER.

ABSTRACT.

The Dillon Nickel Prospect is 23 miles southeast of Dillon, Montana, where a pre-Cambrian ultramafic complex about four and one-half miles long and one mile wide has intruded pre-Cambrian gneiss and schist of the Cherry Creek series. The complex is composed of saxonite, peridotite, nickeliferous serpentine, and related rocks. The chief nickel-bearing mineral is annabergite, found only as incrustations restricted to one intermediate phase of the saxonite. No sulphides were found other than a small amount of pyrrhotite and pentlandite, in a small body of gabbro on one claim. The gabbro assays 0.003 to 0.09 per cent nickel and the ultramafic complex proper 0.15 to 1.25 per cent.

There is large amount of low-grade nickel silicate ore, but the economic possibilities of the annabergite outcrops can only be determined by further prospecting. The area is within easy access to the railroad at Dillon and from the writer's study merits further prospecting.

Location and Topography. The Dillon Nickel Prospect, actually a large ultramafic complex, is approximately 23 miles southeast of Dillon, Montana, in Beaverhead and Madison Counties, and about three and one-half miles east of the graphite deposit described by Winchell.[1] It extends over secs. 1 and 2; T. 9 S., R. 7 W., and secs. 35 and 36, T. 8 S., R. 7 W. According to Winchell, the graphite occurs at the southwestern end of the Ruby Range; however, it appears that both the graphite occurrence and the ultramafic complex under discussion lie in an uplifted block separated from the Ruby Range by the broad Sweetwater Basin which is at least 15 miles wide. The complex is from 7,000 to 8,000 feet above sea level and forms part of a high sagebrush-covered plateau with little relief. The area is accessible from

[1] Winchell, A. N.: Mining districts of the Dillon quadrangle, Montana. U. S. Geol. Surv. Bull. 574: 104, 1914.

Dillon, which is about 65 miles from Butte on highway U. S. 91, and is served by the Union Pacific Railroad.

There are two occurrences of nickel near Dillon, one the Jake Creek "deposit," and the other the Dillon Nickel Prospect. The Jake Creek "deposit," which resembles the latter in being a large ultramafic body with low nickel content, was visited but not examined in detail. This paper deals with the geologic setting, mineralogy, petrology, and commercial possibilities of the Dillon Nickel Prospect.

Previous Work. Rather detailed studies of the nickel occurrence have been conducted in recent years by the Anaconda Copper Mining Company, the results of which are confidential. Maps available are a Beaverhead National Forest Service map (1934) and a United States Geological Survey Reconnaissance map (Dillon quadrangle), 1896.

History. Nickel was first discovered on Jake Creek in the Dillon area, by C. N. Roberts in 1915. This deposit is south of the Dillon Nickel Prospect and across Blacktail Deer Creek. The ultramafic body constituting the Jake Creek deposit strikes N 20° E in Sec 17, and is estimated as about 1,800 feet long and 60 feet wide and is reported to outcrop in many places in the Blacktail Range for a distance of 14 miles south of the original Jake Creek occurrence. The deposit is reputed to contain up to 2 per cent nickel and a trace of platinum.

The Dillon Nickel Prospect was discovered in July 1938 by C. N. Roberts who recognized the close resemblance of the rock types at the latter locality with those of the Jake Creek deposit.

ULTRAMAFIC COMPLEX.

The ultramafic complex forms part of an uplifted block of pre-Cambrian gneiss and schist. It is shaped somewhat like a dumbbell and is about four and one-half miles long, 6,000 feet wide on the southwest end, 3,000 feet wide in the middle and 7,800 on the northeast end (Fig. 1). It trends N 45° E and dips 20° to 30° NW. The complex is bordered on the west and north by pegmatite, aplite, and gneiss, and on the south by gneiss and schist.

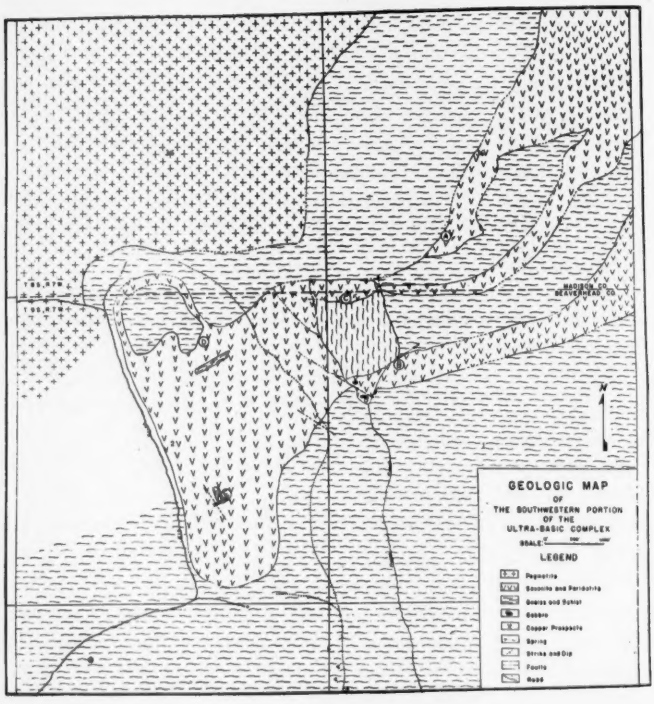

FIG. 1.

A later small body of gabbro is near the Ruby Nickel Claim No. 6. Rocks composing the complex are saxonite, peridotite, nickeliferous serpentine and related ultramafic rocks, many of which have been metamorphosed.

PETROLOGY OF THE ULTRAMAFIC COMPLEX.

Saxonite. The name saxonite was proposed by Wadsworth in 1884, the synonym *harzburgite* being introduced by Rosenbusch in 1885; saxonite is used in this report because of priority. Both names signify a peridotite composed of enstatite or bronzite, and olivine.

Exposures of the complex are limited, and separated by extensive areas of deep overburden; nevertheless, despite local uncertainties in correlation, a continuity of rather distinctive rock types is recognized along the strike of the intrusive. For purpose of record and description, the location of the exposures of the most typical saxonite facies is shown on Fig. 1.

DESCRIPTION OF THE OUTCROPS.

Outcrop A. Saxonite is associated with pyroxenite, enstatolite,[2] hornblende-anthophyllite schist, and serpentinized peridotite.

Outcrop B. This outcrop is noteworthy because of the occurrence of annabergite (a hydrous nickel arsenate) incrusting a rock described in this report as the intermediate phase of the saxonite, being intermediate in composition between saxonite and enstatolite. The remainder of the outcrop is saxonite and enstatolite.

Outcrop C. Saxonite and enstatolite.

Outcrop D. Annabergite is found here under the same conditions as in Outcrop B.

Outcrop E. A small outcrop of saxonite associated with serpentinized peridotite, enstatolite, and anthophyllite schist.

The saxonite is composed of olivine and enstatite in about equal proportions. The olivine is coarse-grained and dark emerald green in color. In thin section it is fresh, and lacks reaction rims or serpentinization. The enstatite crystals range in size from one-quarter inch to two inches in length, and up to one inch in width. No bastite was seen in any of the examined sections. A few scattered needles of anthophyllite were noted in the thin sections and also as veinlets one inch in width traversing the saxonite. Primary magnetite occurs in both the enstatite and olivine; and a chrome spinel is abundant. Differential weathering is characteristic of this rock, with large crystals of enstatite weathering out as nodes in the olivine matrix.

Intermediate Phase of the Saxonite. This rock, intermediate in composition between saxonite and enstatolite, occurs, in Outcrops B and D and perhaps in others. In Outcrop B, it appears about three feet below the surface. As stated before, this rock is

[2] A pyroxenite composed almost entirely of enstatite.

incrusted with annabergite, and seems to be the only rock in the complex containing annabergite.

This intermediate phase exhibits a mineralogical zoning vertically. Where trenching has exposed its contact with the overlying saxonite, there is an 8-inch zone consisting of an aggregate of chrome spinel, a few small crystals of enstatite and olivine, an abundant mixture of anthophyllite and actinolite, and irregular segregations of clinohumite (basic magnesium fluorsilicate).

TABLE I.

SPECTROGRAPHIC ANALYSIS OF INTERMEDIATE PHASE OF SAXONITE WITHOUT VISIBLE ANNABERGITE.

Element.	Estimated Quantity.[3]
Silicon	over 10%
Iron	over 10%
Chromium	1.0%
Aluminum	1.0%
Magnesium	1.0%
Manganese	.1% to 1.0%
Nickel	.1% to 1.0%
Calcium	.1%
Gallium	.01% to 1.0%
Copper	.01% to 1.0%
Sodium	.01% to 1.0%
Zinc	.01% to 1.0%
Cobalt	.01% to 1.0%
Phosphorus	.01% to 1.0%
Titanium	.01%
Lead	.01%
Boron	.001% to 0.01%
Arsenic	.001% to 0.01%
Vanadium	.001% to 0.01%
Silver	.001% to 0.01%

[3] Estimated quantities to the nearest factor of ten.

This zoning terminates rather abruptly in depth against a facies showing thick coatings of annabergite, and minute grains and veinlets of disseminated olivine. Anthophyllite occurs as veinlets and disseminated needles. Actinolite is locally abundant around the edges of the enstatite crystals, and both actinolite and anthophyllite are found around the borders and within the enstatite crystals. The clinohumite in this facies occurs chiefly as compact segregations although there are some grains disseminated throughout the rock. Some of the clinohumite segregations are one and one-half inch in diameter but are more sparsely scattered than in

the first zone. It is a blood red color in the hand specimen but in thin section it displays different shades of orange. Thin sections reveal actinolite in scattered needles around the borders of some of the clinohumite. A nickeliferous chlorite (connarite?), a chrome spinel, and magnetite, are also present in this facies.

A small sample of the intermediate phase of the saxonite, without visible annabergite, was sent to Mr. John Herman, assayer and chemist of Los Angeles for spectrographic analysis. The results appear in Table I.

Attention is called to the relatively small percentage of arsenic, and the 0.1–1.0 per cent nickel. This small content of arsenic may argue against the importance of the hydrothermal introduction of arsenic to produce annabergite, a discussion of which is presented later in this report.

Enstatolite. This rock is composed entirely of enstatite and occurs as veinlets that traverse the saxonite. Texturally, it has a coarse bladed appearance with altered enstatite crystals up to four inches in length. Vermiculite flakes appear along the cleavage faces.

Peridotite. Peridotite appears on the northeastern, and eastern borders, but is more abundant on the western border of the complex. The nickeliferous serpentine is derived from it. Megascopically it is a dark green, fine-grained rock, and is largely altered to serpentine. Biotite, magnetite, olivine, serpentine, and anthophyllite, are readily visible. Microscopically the olivine crystals are surrounded by borders of magnetite and in some cases, iddingsite.

Nickeliferous Serpentine. This striking nickel-bearing rock is found only on the southwestern extremity of the complex. It shows successive stages of alteration of olivine to serpentine, being composed chiefly of a greenish-gray, soapy alteration product of olivine. Anhedral and skeletal crystals of magnetite form incomplete rims around the grains of olivine and anthophyllite, and also form massive veins up to one-half inch in width. Fibrous anthophyllite veinlets cut the serpentine and altered olivine.

Hornblendite. Hornblendite was seen only on the northeast side of the complex near Outcrop A. The rock is dark gray on the weathered surface and has a black metallic appearance on the fresh fracture. It is composed of dark green pleochroic hornblende, and subordinate plagioclase. The plagioclase is intermediate in composition between albite and oligoclase. It is interesting to note that the hornblende of this rock is common hornblende whereas that of the anthophyllite schist is the rather uncommon type, pargasite.

Amphibolite. This rock composed of ferroanthophyllite is found on the western and northwestern extremities of the complex and apparently it is part of the enclosing wall rock. Megascopically it is dark green in color, and shows many small glistening surfaces on the fresh fracture. Microscopically it resembles hypersthene and is distinguished from hypersthene only by X-Ray analysis.[4]

GABBRO AND PEGMATITE INTRUSIVES.

Gabbro. Gabbro occurs on the southeastern side of the ultramafic complex on the Ruby Nickel Claim No. 6. It is a mesocratic, dull, bluish-gray, rock with scattered phenocrysts of plagioclase up to 4 mm. in length which appear to be labradorite although intense saussuritization renders identification uncertain. Augite (var. pigeonite) is present, being altered to chlorite along cleavage faces. Thin sections show a pronounced diabasic texture. Titaniferous magnetite, pyrite, pyrrhotite, and chalcopyrite occur sparingly as accessory minerals.

Pegmatite and Aplite. Granite pegmatite occurs to the west and northwest of the complex, having the form of an inclined sheet striking east-west and dipping north. The rocks weather into prominences, forming brick-red to salmon-colored cliff-like outcrops 50 to 100 feet long and 30 to 35 feet high, for a distance of approximately three miles along the strike. Vertically the pegmatite displays alternate bands of aplite and pegmatite, the

[4] The writer is indebted to Mr. John C. Rabbitt for the X-Ray identification of the ferroanthophyllite.

former being similar mineralogically and in manner of weathering to the pegmatite. The rocks are composed essentially of quartz and orthoclase, with subordinate albite, and possess a graphic texture. Accessory minerals are scattered grains and flakes of magnetite and biotite. The quartz grains are rendered almost opaque by minute inclusions of limonite.

METAMORPHIC ROCKS.

The pre-Beltian metamorphic rocks surrounding the complex merit brief description because of their petrologic interest and the problem of their correlation with the described basement rocks of Montana.

The Pony and Cherry Creek series comprise the pre-Beltian terrane of southwestern Montana.[5] The Pony series (regarded as Archean) is a group of light colored gneisses and schists apparently of both igneous and sedimentary origin, folded and faulted in a complex manner; and presumably underlying the Cherry Creek series.[6] The type section of the Pony series is near Pony, Madison County. The Cherry Creek is an intensely folded series composed of interlaminated gneiss, garnet mica schist, phyllite, marble, quartzite, and crystalline limestone. They lie unconformably beneath the Belt formation and are believed to rest unconformably on the Pony gneiss and schist.[7] The type section is exposed on Cherry Creek in the Gravelly Range, about 16 miles southeast of Ennis. Both the Cherry Creek and Pony series are exposed in the Ruby and Tobacco Root Mountains, which are near the ultramafic complex. According to Winchell,[8] the Cherry Creek series occurs in the area of the Dillon graphite deposit, and it is thought that the same formation also probably occurs near

[5] Studies of the Pony and Cherry Creek series now being made by John C. Rabbitt of Harvard University undoubtedly will add much to the present knowledge regarding these rocks.

[6] Schafer, P. A., and Tansley, W. A.: A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana. Mont. Bur. Mines Geol. Mem. 9: 8, 1933.

[7] Peale, A. C.: U. S. Geol. Surv., Three Forks folio, No. 24, 1896.

[8] Op. cit., p. 23.

the ultramafic complex under discussion. It has been assumed that the Pony series is absent at the complex and that the marked difference in mineral composition between the gneiss and schist directly overlying the complex and those bordering it is due to the injection of the mafic magma of the complex, which reacted with the metamorphic rocks to form minerals somewhat more in equilibrium with the ultramafic magma. In general, the schists and gneisses on the northwestern and southern borders of the complex are slightly more salic in composition and are much more contorted. Many ptygmatic folds occur, and large augen structures are common. One lens of quartzite was found in the gneiss on the northwest side, but no limestone was seen. This series is presumably the lowermost member of the Cherry Creek series.

Petrology of the Metamorphic Rocks.

Anthophyllite Schist. Anthophyllite schist occurs on the southwestern corner of the ultramafic intrusive where evidence of metamorphism and faulting are most pronounced. Megascopically the rock is composed of pale clove-brown anthophyllite, which although generally having a linear arrangement so as to produce a schistose structure, also occurs as aggregates of irregularly disposed prismatic crystals ranging up to five inches in length. Nearly all the crystals of the aggregates are seamed and cracked, but the crystals of the schist itself do not show this fracturing. An unusual feature of the rock is exhibited by films of chrysocolla between the planes of schistosity; however, this is only a local development. Idiomorphic crystals of clinohumite are present in subordinate amounts.

Hornblende-Anthophyllite Schist. This rock is found on the northeastern side of the complex and is composed of pale clove-colored anthophyllite containing injected tongues of chrome-green hornblende (Fig. 2, *C*). The hornblende is pargasite.

Ferroanthophyllite-Garnet Schist. The rock occurs on the northeastern and northern borders of the intrusion. Hand specimens contain abundant ferroanthophyllite with a schistose struc-

ture and characterized by a bluish iridescence. Garnets are abundant and biotite is subordinate.

Garnet-Sillimanite Gneiss. This gneiss overlies the saxonite. It is leucocratic and splinters easily. Quartz and saussuritized plagioclase are present in about equal amounts. Garnet is abundant. Aggregates of acicular sillimanite crystals occur in the quartz (Fig. 2, *E*).

Quartz-Biotite Gneiss. The southern and western borders of the complex are bounded by quartz-biotite gneiss and it is here that the copper prospects occur. A gneissic structure is well de-

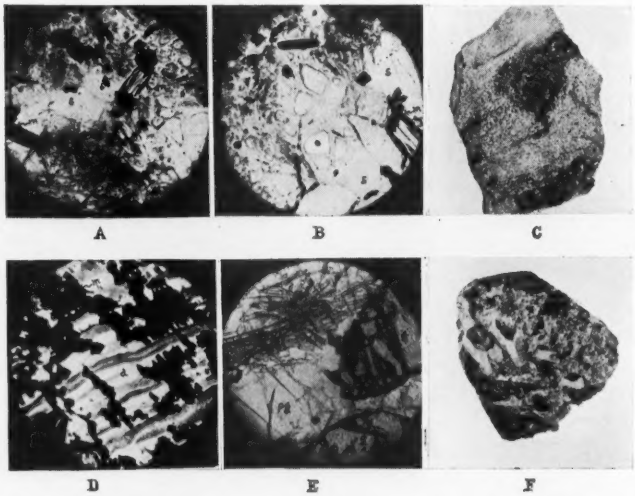

FIG. 2. *A*, Nickeliferous serpentine, magnetite (*m*), serpentine (*s*). Plain light, × 63. *B*, Nickeliferous serpentine, olivine crystals in the center with magnetite borders. Plain light, × 63. *C*, Hornblende-anthophyllite schist, showing tongue of hornblende (dark) projecting into the anthophyllite (light). 1/6 natural size. *D*, Nickeliferous serpentine, anthophyllite (*a*), magnetite (*m*), serpentine (*s*). Plain light, × 63. *E*, Garnet-sillimanite gneiss, garnet (*g*), plagioclase (*pg*), sillimanite crystals in upper left corner. Plain light, × 63. *F*, Garnet-quartz graphic intergrowth, quartz (light), garnet (dark). 1/2 natural size.

veloped, with alternate bands of biotite, quartz and feldspar, and hornblende. Garnet is common, and sillimanite is present as acicular crystals in the felsic bands.

Quartz-Garnet Graphic Intergrowth. This unusual rock occurs on the northeastern corner of the complex, where it forms tongues in the ferroanthophyllite-garnet schist. The exposed part of the rock is in direct contact with the ferroanthophyllite-garnet schist. There is a brecciated and shattered zone of quartz and garnet three-quarters of an inch in width in contact with the schist. This shattered zone contains, with the quartz and garnet, a few scattered flakes and aggregates of ferroanthophyllite that have been torn from the enclosing schist and embedded in the quartz and garnet matrix. There is no slickensliding along the contact but the brecciated zone is undoubtedly a zone of movement between the two rocks. Above the shatter zone, the rock (Fig. 2, *F*) grades into the graphic intergrowth of quartz and garnet which is exposed as an 8-inch zone above which the rocks are covered with soil for 10 to 12 feet, and then the ferroanthophyllite-garnet schist is again exposed. Under a binocular microscope, a polished surface of the rock shows minute rounded garnets and a black opaque mineral, probably magnetite. Several small green crystals having the form of apatite were seen in the quartz. The garnet is massive and ranges in color from dark mahogany-red or reddish-purple to dark pink; it is almandite. Where in contact with the quartz the garnet shows imprints of the horizontal striations and corrugated surfaces of the quartz crystals. This evidence of the striated surfaces of the garnet strongly suggests the priority of the quartz.

STRUCTURAL GEOLOGY.

The complex is exposed on a steep hillside near Elk Creek for about 1,000 feet and there is no indication of a floor. Since it is overlain by schists and gneisses and since no floor has yet been found the term "chonolith"[9] is used to describe the form of

[9] Daly, R. A.: Igneous Rocks and the Depths of the Earth. McGraw-Hill Book Company, Inc., p. 105, 1933.

the complex until such time as additional field work may prove otherwise. The fact that sizable xenoliths of gneiss and schist are rotated considerably from the original northeast strike, indicates that during intrusion the mafic magma had sufficient viscosity to dislodge and rotate the xenolithic blocks. The largest xenolith is 1,280 by 500 feet and the smallest observed is 100 by 40 feet. The ultramafic exposures on Jake Creek suggest a sheetlike peridotite body with the same general northeast trend as the main complex.

The petrologic similarity of the intrusives of the Dillon area and those of Jake Creek suggest a common origin, and the probability of a deep-seated connection between these apparently related rocks.

ECONOMIC GEOLOGY.

The Dillon Nickel Prospect is a considerably metamorphosed nickeliferous ultramafic complex of pre-Cambrian age, composed of saxonite, peridotite, nickeliferous serpentine, and related ultramafic rocks. A small body of gabbro on the Ruby Nickel Claim No. 6 is the only rock in the complex containing a nickel sulphide. Elsewhere in the complex the nickel-bearing mineral is annabergite, occurring only with the intermediate phase of the saxonite.

The Nickel-Bearing Minerals.

Nickel Arsenate. The nickel arsenate, annabergite, occurs as an incrustation on the intermediate phase of the saxonite, and is found eighteen inches below the surface in Outcrop D, and three and one-half feet below the surface in Outcrop B, Fig. 1. The writer first believed the Dillon annabergite to be cabrerite because of the presence of magnesium in the analysis (Table II).

Known annabergite from Sudbury, Ontario, closely resembles the Dillon mineral microscopically; however, since annabergite and cabrerite have closely similar optical properties their distinction is difficult. The Sudbury annabergite occurs as an incrustation on niccolite, whereas the Dillon occurrence is only on the intermediate

TABLE II.

Per Cent.	Annabergite Schneeberg.	Annabergite Silver Cliff.	Annabergite Dillon.[10]	Cabrerite Spain.
As_2O_5	38.30	36.64	44.11	42.37
NiO	36.20	32.64	28.71	20.01
MgO		3.74	2.19	9.29
CaO	Trace	3.51	Not tested	
CoO	1.53	0.05	Not tested	4.06
FeO	Trace		Not tested	
H_2O	23.91	23.94	0.60	25.80
Total	99.94	100.52	75.61	101.53

[10] H. J. Harrity, analyst, Anaconda Copper Mining Co., Butte, Montana. Others from Danas' System of Mineralogy, 1837–1868.

phase of the saxonite, which is niccolite free. This difference in occurrence may account for the magnesium in the Dillon mineral, although extreme care was taken to obtain a pure sample.

It is to be noted that the percentages of As_2O_5 and NiO of the Dillon annabergite are very close to that of the cabrerite from Spain. Because of the presence of magnesium and the close resemblance chemically between the annabergite and cabrerite, a further check seemed advisable, and thus a sample of the mineral was sent to the United States Geological Survey. Dr. M. Fleischer of the Chemical Laboratory reported as follows:

> The green nickel mineral present as an incrustation on specimens 1 to 6 and 1 to 7, is annabergite, not cabrerite. It was not possible to measure the refractive indices accurately, because the mineral is microcrystalline, but the mean index was so high that it seemed improbable that an appreciable quantity of magnesium was present. As a check, an analysis was made of 21.6 milligrams of carefully purified material. This gave 34 per cent NiO, which confirms the belief that the mineral is close to the pure nickel end member of the series. Dr. Barth showed by optical study that the so-called cabrerite from Laurium, Greece, could not contain as much magnesium as the analysis showed. However, the type cabrerite from Spain has never been studied optically, and it may be that the analyses of it are correct.

Origin of the Annabergite. Mineralogists are apparently unanimous in the belief that annabergite is formed as an oxidation product of niccolite or other nickel arsenides, and always occurs in close association with these minerals, either as incrustations or

in a manner clearly establishing a genetic relationship. At Dillon, however, the origin of the annabergite is perplexing since no trace of primary arsenides is evident, even as pseudomorphs.

The following hypotheses are offered as reasonable possibilities for the origin of the annabergite on the basis of its mode of occurrence and the geologic events affecting the area:

(1) Niccolite or some other nickel arsenide present in the ultramafic magma crystallized as disseminated grains throughout a layer in the saxonite. Upon exposure, the minerals were completely transformed to annabergite.

(2) The nickel was originally part of the olivine and enstatite molecules and was liberated by hydrothermal solutions which furnished requisite arsenic for annabergite formation; and also perhaps transferred both nickel and arsenic, thus making annabergite hydrothermal and not unlike (3) in mode of occurrence.

(3) The annabergite is hydrothermal, both nickel and arsenic being introduced by solutions which permeated the intermediate phase of the saxonite, the solutions emanating from the gabbro or the ultramafic body.

Lacking the evidence of a former existence of primary arsenides, the author favors either the second or third hypothesis with preference for the former. Although quite similar (both involving hydrothermal activity) there appears to be sufficient nickel in the olivine and enstatite molecules to supply that requisite for annabergite formation.

Possible Sources of Nickel Other Than Annabergite.

With regard to the occurrence of nickel in the peridotite, saxonite, and serpentine of the Dillon complex, the findings of Vogt and others on the occurrence of nickel in basic and ultramafic rocks are significant. According to Vogt,[11] nickel derived from pyrrhotite disseminated in mafic rock probably does not exceed 0.002 per cent in any determination and in most cases is less than 0.001 per cent. Vogt reports the nickel content of the Norwegian norites known to contain nickeliferous pyrrhotite as follows:

[11] Vogt, J. H. L.: Nickel in igneous rocks. Econ. Geol., 18: 309, 1923.

TABLE III.

Name.	Per Cent Nickel.*
Norite	0.023
Olivine norite	0.093
Amphibole peridotite	0.124
Norite	0.030
Hypersthene norite	0.058
Hypersthene norite	0.070
Segregations of ferromagnesian silicates rich in hypersthene	0.126
Olivine gabbro	0.067

* These analyses are as free of sulphides as possible.

TABLE IV.

AVERAGE CONTENT OF NICKEL IN IGNEOUS ROCKS.[12]

Peridotite	0.14 Ni.
Pyroxenites	0.08 Ni.
Norites	0.035 Ni.
Olivine free gabbros	0.030 Ni.

[12] Op. cit., p. 327.

TABLE V.

NICKEL CONTENT OF ROCKS FROM THE DILLON PROSPECT.[13]

Gabbro	0.003 Ni.
Gabbro	0.09 Ni.
Peridotite	0.16 Ni.
Saxonite	0.20 Ni.
Olivine dunite	0.00 Ni.
Olivine dunite	0.03 Ni.
Nickeliferous serpentine [14]	0.40 Ni.

[13] H. J. Harrity, analyst, Anaconda Copper Mining Co., Butte, Montana.
[14] Dr. M. Fleischer, analyst, U. S. Geol. Surv., Chem. Lab., Washington, D. C., Personal communication.

The analyses show that nickel is present in the olivine and related mafic rocks, and it is probable that the nickel in the serpentine, saxonite, peridotite, and related rocks at the Dillon ultramafic complex is a primary component of the olivine and enstatite molecules. It is of note that no garnierite has yet been identified at the ultramafic complex in any of the rocks studied by the writer.

Pyrrhotite and Pentlandite. Pyrrhotite occurs in very small quantities in the gabbro, which is the only rock in the area bearing recognizable sulphides. One and one-half pounds of the gabbro were ground to —80 mesh and the sulphides were separated by flotation, sufficient sulphide being obtained in this manner to make two bakelite briquettes. The briquettes were stained with the

standard chromic-hydrochloric acid solution.[15] Staining revealed that the briquettes are composed of pyrite, chalcopyrite, magnetite, and pyrrhotite and pentlandite. In an area containing 300 grains only 14 are pentlandite, 23 pyrrhotite, and the remainder pyrite, chalcopyrite, and magnetite.

Pyrite occurs in the gabbro and sparingly in the peridotite. Some of the grains are entirely enclosed by magnetite, others cut the magnetite, and still others occur as disseminations through the silicates of the gabbro.

Chalcopyrite occurs alone in the silicates of the gabbro.

Chrome spinel occurs in the intermediate phase of the saxonite as grains in the clinohumite, enstatite, etc.

Titaniferous Magnetite. This mineral occurs in the gabbro and to some extent in the peridotite. Ilmenite cuts across the magnetite grains and follows the octahedral faces of the magnetite. These lamellae are so small that they can scarcely be seen under the highest magnifications. The lamellae are very numerous and closely spaced in some cases, in others they are few in number and widely spaced. The ilmenite intergrowths are too minute to permit mechanical separation from the magnetite, but are present in sufficient quantity to give it a considerable titanium content. Polished surfaces of the magnetite were etched with hydrochloric acid, and the relations of the two minerals were clearly disclosed. Some of the magnetite after etching did not show any ilmenite but when carefully tested with HCl and zinc gave a reaction for titanium.

Magnetite. The magnetite of the nickeliferous serpentine does not show the characteristic color of polished magnetite but has a coppery-pink color characteristic of niccolite. In the hand specimen it appears to have a purplish color. The color may be due to the presence of titanium, a trace of which is present in the magnetite as shown by spectrographic analysis.

Chrysocolla occurs sparingly along the planes of schistosity in the anthophyllite schist.

[15] Gaudin, A. M.: Staining minerals for easier identification in quantitative mineragraphic problems. ECON. GEOL. 30: 552–562, 1935.

ECONOMIC POSSIBILITIES.

Basic factors to be taken into consideration in appraising the economic possibilities of the Dillon nickel occurrence are the vertical and horizontal extent of the deposit, quantity and quality of the ore, metal prices, and methods of separation.

The complex is four and one-half miles long and from 3,000 to 7,800 feet wide, and on the southwest end is exposed on a steep hillside for a vertical distance of 1,000 feet and no floor is in sight. The ultramafic complex is a body of low-grade material containing at least some of the nickel as Ni_2SiO_4. Grab samples from Outcrop D (Fig. 1) on the Nickel Mountain group of claims, assay from 0.15 to 1.25 per cent nickel. Systematic samples taken from Outcrop A and northeast, yielded assays ranging from 0.04 to 0.26 per cent nickel.

The annabergite in the purified form assays 28.71 to 34 per cent NiO.

An unlimited supply of low-grade nickel silicate-bearing rock occurs at the Dillon Prospect. Since the surface has barely been scratched, the economic possibilities of the annabergite outcrops can only be determined by further prospecting. Tunneling or diamond drilling might possibly reveal nickel arsenides or sulphides at depth.

ACKNOWLEDGMENTS.

The author wishes to express her appreciation to Dr. George F. Seager of the Department of Geology, Montana School of Mines, for his interest and help during the work. The writer is also indebted to Dr. Esper S. Larsen, of Harvard, for his stimulating discussion in the field and for suggesting changes and corrections in the manuscript; to Mr. John C. Rabbitt, of Harvard, for his helpful criticisms and checking of minerals; and to Dr. M. Fleischer and Miss Jewell Glass, of the United States Geological Survey, for their analytical work and assistance in certain mineral identifications.

BUTTE, MONTANA,
Jan. 2, 1942.

DISCUSSION AND COMMUNICATIONS

CHROMITE DEPOSITS OF CALIFORNIA.

Sir: Mr. F. G. Wells in his review of J. E. Allen's bulletin on Chromite Deposits of California in the September 1941 issue of this journal claims that "Allen's emphasis on linear structural control results from a method of analysis consequent on the arbitrary method of defining a locality that gives a distorted picture of structural regularity." The definition of a locality that he refers to is presumably the one limiting a group to deposits not more than a quarter of a mile apart. That this does not necessarily invalidate the theory of structural control for chromite deposits propounded by Allen is well shown in the two principal chromite fields of the Philippines. Owing to their recent development little detailed geological study has been carried out but all of Allen's main conclusions apply, and linear structural control is pre-eminent.

Thus in the Zambales field the known belt of chromite deposits is 25 kilometers long in a north-south direction and up to one kilometer wide with lenses aligned in parallel shear zones, and the longer of their two horizontal axes generally north-south, although recent development at depth shows that at least some of the deposits are better described as steeply inclined pipes. The importance of the field may be gauged from the reserves of 10,000,000 tons of refractory chromite (here a spinel with 33% Cr_2O_3) at the Masinloc Mine, and 600,000 tons of metallurgical and chemical ore at the Acoje Mines. At this latter property much of the ore consists of a high-grade chromite mineral disseminated in a serpentinised matrix although in places the chromite forms rounded concentrations, which on the weathering out of the matrix have the size and appearance of bunches of grapes. The

origin of the disseminations is uncertain but Allen's suggestion of hydrothermal solutions seems applicable.

In the Province of Oriental Misamis, Mindanao, a new field is being developed in which linear structural control is strikingly illustrated by the majority of the known chromite deposits lying along a straight line striking north-east for 20 kilometers and characterized by a strong shear zone. This direction is that of the structural grain of this section of Mindanao, which also contains two parallel belts of gold deposits, another of manganese, and an intrusive granite elongated in the same north-east direction.

It is interesting to note that in the historical development of ideas concerning the origin of ore deposits, the emphasis at one time was placed on the physico-chemical nature of the ore-bearing fluids and the apparently great difference between the pyrogenic deposits such as chromite and the more usual hydrothermal deposits. More recently the emphasis has shifted to the importance of structural control in the deposition of hydrothermal ore-deposits, and now mining geologists, such as Allen, who are turning their attention to the strategic mineral chromite are finding that structural control is of equal importance, and moreover that in some cases at least a hydrothermal origin is not incompatible with the field evidence.

A. C. SKERL.

INTERNATIONAL ENGINEERING CORPORATION,
MANILA, PHILIPPINES,
Nov. 12, 1941.

REVIEWS*

Possible Future Oil Provinces of the United States and Canada. Edit. by A. I. LEVORSEN. Pp. 154; 83 line drawings. Amer. Assoc. of Pet. Geol., Box 979, Tulsa, Okla., 1941. Price, $1.50.

This volume is the result of a symposium conducted by the Research Committee of the American Association of Petroleum Geologists at the Houston, Texas, meeting, April 1, 1941. It constitutes a cooperative enterprise in which numerous geologists and geological organizations participated to focus attention on possible future oil provinces of North America north of the Rio Grande. By definition, untested areas lying within presently producing provinces are excluded. The survey is confined to "those outlying areas which have in the past been only partly explored and in which discoveries of any consequence have yet to be made."

The criteria here uniformly applied to "undiscovered oil provinces" are:

1. *Sediments.*—The character and volume of sediments in each selected area are scrutinized. Areas known to have a sedimentary section of less than 1,000 feet are not considered; the lower limit of computation is approximately 15,000 feet, the present accepted maximum depth of economic drilling.

2. *Known Evidences of Oil and Gas.*

3. *Unconformities.*—". . . a known regional unconformity within an area increases the chances of finding favorable petroleum geology because it overlies and hides a new and unknown set of geologic conditions. . . . Thus an area with two or three known regional unconformities is two or three times more favorable to ultimate oil discovery than an area with none."

4. *Wedge Belts of Porosity.*—Since wedge belts of porosity determine the type of reservoir in the East Texas field, in the Bartlesville sand province, and elsewhere, the possibility of similar conditions in these untested areas is weighed.

The volume constitutes a valuable compilation of geologic data within the prescribed limits. It is especially useful for having been distilled from many sources by many men and assembled in comparable form for each

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

individual district considered. The maps and sections, over 80 in number, are of especial interest. Few have appeared previously in the same form. Generally they represent compilations of geologic data from various sources, conveniently combined to set forth features of geology and structure bearing on the search for oil.

The appearance of the volume is timely. Our known reserves of oil are being depleted at an accelerating pace for war use. The burden of discovery of new oil falls squarely on the geologist, and he will welcome the suggestive data herewith presented.

W. E. WRATHER.

The Development of Mineral Industry Education in the United States. By THOMAS THORNTON READ. Pp. xiv and 298; Pls. 26. Am. Inst. Min. and Met. Engrs., Seeley W. Mudd Series. New York, 1941.

The third book of the series financed by the Seeley W. Mudd Fund differs from its predecessors in that it is a historical survey rather than a compendium of knowledge about a group of minerals.

The book confines itself to the development of education for the mineral industries in the United States, partly because of the limited time at the author's disposal, partly because of the fact that more than half of the better mining schools are located in this country, and partly because education for the profession of mining engineering has been brought to its highest form of development in North America.

The main reason for the study, so the author states in his preface, was "the hope of benefiting young engineers through contributing to the development of better educational institutions for them." This admirable purpose is developed in the final chapter, which is entitled "Summary," but which proves to be the recapitulation of the trends of our educational system plus a good exposition of one school of educational philosophy. The author argues in a convincing manner that mining engineering should not be considered a branch of other engineering since it requires the fundamentals of geology and mineralogy, which are quite foreign to other engineering courses. Therefore, although separate schools of mines have not in general proven to be the most successful method in handling education for the mineral industry, (most so-called "schools of mines" are actually complete engineering schools) he advocates that the ideal goal should be separate schools, which would be not only for mining engineering but for the whole mineral industry. Such schools should endeavor to teach underlying fundamentals rather than to concern themselves too much with "practical experience," which can really only be gained after graduation.

This chapter contains the real worth and essence of the book, and should prove very interesting to all connected with economic geology, mining, or metallurgy.

The rest of the book, however, does not measure up either in content or in treatment to this final chapter. Its style is that of a scientific report on a laboratory experiment rather than a historical treatise. Such a straightforward style has proven its value in the older type of scientific textbooks, which are in general more successful than the newer popularized texts, but when applied to a subject such as this, it is resolved into a mere listing of facts and dates. Starting with the early period of American schools, each chapter deals with a certain span of years and gives data for various colleges and universities for the period. The data usually consists of the names of professors, courses offered, and number of pupils. Any interesting information is thus well buried beneath a mass of names, dates, parentheses, and abbreviations, and the expectable soporific effects of 273 such pages are quite pronounced. Much of the data might have been relegated to a large table or appendix.

Due to this unfortunate style and treatment the book will have little appeal to anyone except those directly concerned with the educational problems of schools of mines and geology. It has no appeal to the layman, and the average scientific reader will probably be discouraged long before he reaches the excellent final portion. For this reason it may not reach as many people as it should.

There has been a need for this type of book in the mineral industry, and it is to be hoped that the detriments will not prevent its potential value from being realized. Despite this underlying worth, however, and despite Herbert Hoover's comment that it "does honor to the profession and has contributed to strengthen its foundations," this volume is somewhat of a disappointment when compared with its predecessors in the Seeley W. Mudd Series.

WILLIAM E. BENSON.

Geophysics in War. By C. A. HEILAND. Pp. 85; Figs. 37. Colorado School of Mines Quarterly, Vol. 37, No. 1. January, 1942.

The primary objective of this publication is to show how the many applications of geophysical science and technology—principally those of exploration geophysics—are being turned to war uses. Dr. C. A. Heiland, Professor of geophysics at the Colorado School of Mines, has written a bulletin which is concise in statement, simple and non-mathematical in exposition of the principles and techniques, and quite thorough in its coverage of the essential applications of geophysics to war.

The author divides the paper into two parts: Military Operations, and Mineral Resources. The first group, on military applications, deals with the methods of artillery and submarine detection, depth sounding, radio detection of buried munitions or metallic objects. Of particular importance are the techniques of foundation testing for the locations of fortifications or munitions factories by seismic or resistivity methods.

The section on mineral resources contains a brief description of the geologic occurrences of the strategic minerals, with the various methods of geophysical exploration that may be used for each.

The publication should be of value to those directly occupied with war activities as an outline of the many ways in which geophysical methods may be utilized. To the geophysicist it should point out the particular needs for his special training in wartime.

Adequate footnotes are given to more technical works on the various aspects treated, especially to the author's own authoritative book, "Geophysical Exploration."

J. I. TRACEY, JR.

The Mines Magazine, Sixth Annual Petroleum Edition. Pp. 90. Mines Mag., vol. 31 (9). Denver, 1941. Price, $1.00.

The annual petroleum edition of the magazine of the Colorado School of Mines Alumni Association is always something more than just another issue of this well-known periodical, and this year's number is no exception. The table of contents gives some idea of the varied aspect of the subject matter.

1. The Petroleum Industry in the National Defense Emergency. JOHN R. SUMAN.
2. The Lance Creek Oil Field. B. H. ANDERSON AND HUGO RIECKEN.
3. Distillate Recovery Combined with Pressure Maintenance. R. C. FISH.
4. Gravity Work in Illinois. W. W. SKEETERS.
5. Characteristics of the Oil and Gas Fields of the Rocky Mountain District. E. W. KRAMPERT.
6. Developments in Pressure Coring Practice. I. S. SALNIKOV.
7. Operations of the Production Dept., Tropical Oil Co., Colombia, South America. B. F. ZWICK.
8. The Zenith Pool of Stafford and Reno Counties, Kansas. JOHN T. PADDLEFORD.
9. The Gravity Meter in Colombia. H. J. MCREADY.
10. The Shale Oil Industry in Estonia. PAUL KENTS.
11. Development of Radioactivity Well Logging Through Casing. W. L. RUSSELL.

12. The Importance of Stratigraphic Traps in Petroleum Geology. A. H. DUCLOUX.
13. Petroleum Engineering, Colorado School of Mines. H. M. CRAIN.
14. Safety in Numbers. RUFUS M. SMITH.

The opening article by John R. Suman deals chiefly with our petroleum reserves and production capacity as related to the present world situation. In spite of the fact that this was written before the formal entry of the United States into the war, most of this article is still very pertinent.

Of the remaining thirteen articles, Nos. 10 and 12 should be of particular interest. No. 10, *The Shale Oil Industry in Estonia,* describes the European development of this source of petroleum, all but forgotten in this country. No 12, on the importance of stratigraphic traps, is an excellent exposition of the trends of thought of many oil geologists during the past few years.

Article No. 4 summarizes the stratigraphic and structural features of some 70 producing districts of Wyoming, and should be valuable as a ready reference.

W. E. B.

BOOKS RECEIVED.

WILLIAM E BENSON.

Aerial, Geological, and Geophysical Survey of Northern Australia. Additional papers in the series of short reports on various mining areas of Australia. This interesting series first listed in this journal, Jan., 1940. All published at Canberra; probably 1940. The following have been received recently:

NORTHERN TERRITORY REPORTS.

No. 22. **The Ciccone Mine, Winnecke Gold-Field, Eastern Macdonnell Ranges District.** P. S. HOSSFIELD. Pp. 5; geol. map in color.

No. 39. **The Glankroil Mine, Winnecke Gold-Field, Eastern Macdonnell Ranges District.** P. S. HOSSFIELD. Pp. 2; geol. map in color.

No. 40. **The Winnecke Gold-Field, Eastern Macdonnell Ranges District.** P. S. HOSSFIELD. Pp. 7; maps 1. More general report, covering whole field. *Published under one cover with Nos. 22 and 39.*

WESTERN AUSTRALIA REPORTS.

No. 17. **The Sharks Well Mining Centre, Pilbara Gold-Field.** K. J. FINUCANE. Pp. 3; maps 2. *Under one cover with No. 26.*

No. 22. **The Boodalyerrie Mining Centre, Pilbara Gold-Field.** K. J. FINUCANE. Pp. 3; geol. map in color.

No. 23. **The Yandicoogina Mining Centre, Pilbara Gold-Field.** K. J. FINUCANE. Pp. 6; pls. 3, inc. geol. map in color.

No. 24. **The Braeside Lead Field, Pilbara District.** K. J. FINUCANE. Pp. 7; pls. 4; geol. map in color.

No. 26. **The Country between Sharks and North Shaw, Pilbara Gold-Field.** F. H. JONES. Pp. 2; geol. map in color. *Under one cover with No. 17.*

No. 27. **The Hall's Creek-Ruby Creek Area, East Kimberly District.** K. J. FINUCANE. Pp. 9; pls. 4; geol. map in color. *Under one cover with Nos. 41 and 42.*

No. 29. **The Mount Dockerell Gold Mining Centre, East Kimberly District.** K. J. FINUCANE. Pp. 5; pls. 2, inc. geol. map in color. *Appendix on Christmas Creek Area by C. J. Sullivan.*

No. 34. **The Chromite Deposits of Coobina, Peak Hill Gold-Field.** K. J. FINUCANE. Pp. 2; maps 1.

No. 41. **The Mary River Gold Mining Centre, East Kimberly District.** K. J. FINUCANE AND C. J. SULLIVAN. Pp. 2; pls. 2, inc. geol. map in color. *Under one cover with Nos. 27 and 42.*

No. 42. **The Twelve-Mile Alluvial Workings and Elvire River Dredging Reserves (893H and 948H), Hall's Creek, East Kimberly District.** K. J. FINUCANE. Pp. 2. *Under one cover with Nos. 27 and 41.*

QUEENSLAND REPORTS.

No. 15. **The Mount Oxide Copper Mine, Cloncurry District.** C. S. HONMAN. Pp. 7; pls. 3; geol. map in color. *Under one cover with No. 20.*

No. 19. **The Bower Bird Auriferous Area, Cloncurry District.** C. S. HONMAN. Pp. 10; pls. 2, inc. geol. map in color.

No. 20. **The Mount Oxide Area, Cloncurry District.** C. S. HONMAN. Pp. 7; pls. 2; geol. map in color. *Under one cover with No. 15.*

Nos. 23 and 51. **The Tin Deposits of the Stanhills Area, Croydon Gold and Mineral Field.** R. J. S. CLAPPISON AND H. I. JENSEN. Pp. 23; pls. 2, inc. geol. map in color. *Under one cover; No. 51 is a complimentary report to No. 23.*

No. 34. **The Cobalt Deposits of the Cloncurry District.** E. O. RAYNER. Pp. 26; pls. 3; figs. 4; geol. map in color, scale 1″ = 80 ft. *Describes geology and mining operations. Larger scale production from this area may be possible.*

Aerial, Geological, and Geophysical Survey of Northern Australia, Report for Period ended December 31, 1939. Pp. 57; pls. 9. Canberra, 1940. *Summarizes results of investigations carried on in Queensland, Western Australia, and Northern Territories.*

Geology and Oil and Coal Resources of the Region South of Cody, Park County, Wyoming. W. G. PIERCE AND D. A. ANDREWS. Pp. 75; pls. 14; figs. 4; geol. map in color, 21″ × 42″, scale 1 : 63,360. U. S. Geol. Surv., Bull. 921–B. Washington, 1941. Price, $1.00. *A very fine report, giving detailed stratigraphic and structural relations of the formations in the area. Photographs labelled to show structural features are especially good.*

Tin-Bearing Pegmatites of the Tinton District, Lawrence County, South Dakota. W. S. SMITH AND L. R. PAGE. Pp. 36; pls. 5; figs. 4; 3 geol. maps in color. U. S. Geol. Surv., Bull. 922–T, Prelim. Rept. Washington, 1941. Price, $1.00. *Excellent maps with plans and sections of mines.*

Superposition in the Interpretation of Two-Layer Earth-Resistivity Curves. I. ROMAN. Pp. 18; pls. 2; figs. 2; tables 2. U. S. Geol. Surv., Bull. 927–A. Washington, 1941. Price, 30 cents. *A method for interpretating data on electrical resistivity by the superposition of field curves on standard curves of reference.*

Subsurface Geology and Oil and Gas Resources of Osgae County, Oklahoma. U. S. Geol. Surv., Bull. 900. Published in several sections; the following new parts have been received:

900–G. **Part 7. Townships 20 and 21 N., Ranges 11 and 12 E.** W. R. DILLARD, N. W. BASS, AND C. T. KIRK. Pp. 32; subsurface map, scale 1″ = 1 mile. Washington, 1941. Price, 30 cents.

900–H. **Part 8. Parts of Township 20 N., Ranges 9 and 10 E, Township 21 N., Ranges 8 and 9 E., and All of Township 21 N., Range 10 E.** C. T. KIRK, W. R. DILLARD, O. LEATHEROCK, AND H. D. JENKINS. Pp. 34; subsurface map, scale 1″ = 1 mile. Washington, 1941. Price, 35 cents.

900–I. Part 9. **Townships 23 and 24 N., Range 7 E.** N. W. BASS, W. R. DILLARD, L. E. KENNEDY, AND H. B. GOODRICH. Pp. 17; subsurface map, scale 1″ = 1 mile. Washington, 1941. Price, 25 cents.

Petroleum and Natural Gas Fields in Wyoming. R. H. ESPACH AND H. D. NICHOLS. Pp. 176; figs. 72; tables 8; numerous chemical analyses. U. S. Geol. Surv., Bull. 418. Washington, 1941. Price, $2.25. *Brief reviews with structure maps of each field. The high price is due to the numerous large maps included in separate case.*

Warren County Mineral Resources. F. F. MELLEN, T. E. MCCUTCHEON, AND M. R. ROGERS. Pp. 132; pls. 7; figs. 12; tables 20; 4 histograms. Miss. Geol. Surv., Bull. 43. University, 1941. *General geology, which consists mainly of stratigraphy, followed by laboratory tests on clays, marls and limestones. Resources limited to non-metallics.*

Noranda District, Quebec. M. E. WILSON. Pp. 148; pls. 14; figs. 3; 5 geol. maps in color, scale 1″ = 800′. Canada Geol. Surv., Memoir 229. Ottawa, 1941. Price, 50 cents. *General geology plus descriptions of the mines.*

Illinois Mineral Industry. Part I—In 1940; Part II—Historical Summary, 1919–1939. W. H. VOSKUIL AND G. N. OLIVER. Pp. 89; figs. 6; tables 75. Illinois Geol. Surv., Rept. Invest. No. 74. Urbana, 1941. *Chiefly statistical.*

Past Lode-Gold Production from Alaska. P. S. SMITH. Pp. 53; figs. 1; tables 5. U. S. Geol. Surv., Bull. 917–C. Washington, 1941. Price, 10 cents.

Geology and Ground-Water Resources of the Balmorhea Area, Western Texas. W. N. WHITE, H. S. GALE, AND S. S. NYE. Pp. 62; pls. 1; figs. 2; numerous tables. U. S. Geol. Surv., W. S. P. 849–C. Washington, 1941. Price, 15 cents.

SCIENTIFIC NOTES AND NEWS

The AMERICAN LIBRARY ASSOCIATION COMMITTEE ON AID TO LIBRARIES IN WAR AREAS has asked the Journal to print the following on conservation of scholarly Journals: The Committee is faced with numerous serious problems and hopes that American scholars and scientists will be of considerable aid in the solution of one of these. One of the most difficult tasks in library reconstruction after the first World War was that of completing foreign institutional sets of American periodicals. Many sets will be broken by financial inability of the institutions to renew subscriptions. As far as possible they will be completed from a stock of periodicals being purchased by the Committee. Many more will have been broken through mail difficulties and other sets will have disappeared in the destruction of libraries. Requests already received by the Committee give evidence that the size of the eventual demand will be enormous.

With an imminent paper shortage attempts are being made to collect old periodicals for pulp. Fearing this possible reduction in the already limited supply of scholarly and scientific Journals, the Committee hopes to enlist the cooperation of subscribers to this Journal in preventing the sacrifice of this type of material to the pulp demand. Questions concerning the project should be directed to Wayne M. Hartwell, Rush Rhees Library, University of Rochester, Rochester, New York.

E. L. DEGOLYER was presented the John Fritz Medal by the A. I. M. E. at a dinner in New York City on January 14th.

G. C. BRANNER, State Geologist of Arkansas, has been called to active duty as Lt. Colonel in the Quartermaster Corps, U. S. Army. R. J. ANDERSON has been appointed acting State Geologist during the absence of Mr. Branner.

The AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, the SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS and the SOCIETY OF EXPLORATION GEOPHYSICISTS will hold joint sessions at the Cosmopolitan Hotel, Denver, Colorado, April 22–24. The Rocky Mountain Association of Petroleum Geologists is serving as host for the meetings. Special conferences have been arranged to consider various essential problems of the war effort.

C. K. LEITH, adviser to the Materials division of the U. S. War Production Board, is giving a series of ten lectures at Columbia University, Feb. 16–March 23, on Minerals in Peace and War. These lectures to which the public is invited are given under the auspices of the Division of Geology and Geography of Columbia University. The three final lectures on March 16, 17 and 23 will be discussions of possible programs for a mineral policy directed toward international peace and stability.